Environmental Science and Pollution Research (2020) 27:20736–20747
https://doi.org/10.1007/s11356-020-08372-5

RESEARCH ARTICLE

Analysis of asymmetries in the nexus among clean energy and environmental quality in Pakistan

Ahmed Usman[1] · Sana Ullah[2] · Ilhan Ozturk[3] · Muhammad Zubair Chishti[2] · Syeda Maria Zafar[4]

Received: 25 December 2019 / Accepted: 9 March 2020

Abstract

This study examines the short-run and long-run asymmetric effects of clean energy consumption on carbon emission in Pakistan, over the annual time period 1975–2018, by using a non-linear ARDL approach. The findings of the study confirm the existence of asymmetries, in the nexus between the clean energy consumption and carbon emission in the short and long run. The findings of non-linear model confirm that carbon emission responded contrary to positive shocks of energy variables as compared with their negative shocks. Asymmetric findings recommend that positive and negative shocks of the alternative and nuclear energy and combustible and waste energy have affected differently. Although, short- and long-run results suggest an insignificant positive and negative relationship between electric power consumption and carbon emissions. Therefore, more taxation of non-renewable energy and clean energy supports are suggested for the Pakistan economy. We concluded that Pakistan has potential in clean energy which will improve environmental quality in the near future.

Keywords Clean energy · Nuclear energy · Renewables and waste energy · CO_2 emissions · Non-linear ARDL · Pakistan

Introduction

In Pakistan, urbanization and growth of the population have led to energy demand. This tendency has also been observed in the last few decades in Pakistan. However, in order to get sustainable economic growth, the demand for energy is quite high which has threatened the natural environmental balance (e.g., global warming, deforestation, air pollution, and water pollution) in Pakistan. The growing level of unclean energy consumption in Pakistan has led to initiate an investigation of its impact on carbon emissions that may contribute to global warming because the mode in which we consume energy impacts society's environmental quality. Moreover, macro-instability and oil shock of 2008 affect the price of fuels and increasing greenhouse gases inspired to find clean energy sources including nuclear, biomass and biofuel, and electric power energy. Therefore, the Pakistan government has been following environmental policies to encourage solar, nuclear, biomass and biofuel, and electric power energy.

The clean energy sources are biomass, biofuels, hydropower, geothermal, wind, nuclear, solar, and sea wave energy, respectively. Therefore, clean energy might decrease energy dependency and energy security, and improve environmental quality. Besides, clean energy offers a solution for natural problems of climate change, global warming, acid rains, loss of biodiversity, air pollution, and water pollution because clean energy might slacken carbon emissions and other pollutant gas emissions (Georgescu et al. 2011; Apergis and Payne 2012; Danish et al. 2017; Shahbaz et al. 2017; Zoundi 2017; Ullah et al. 2020). Thereby, clean energy can increase

Responsible editor: Muhammad Shahbaz

✉ Sana Ullah
sana_ullah133@yahoo.com

Ahmed Usman
voice.of.usman.au@gmail.com

Ilhan Ozturk
ilhanozturk@cag.edu.tr

Muhammad Zubair Chishti
mzchishti@eco.qau.edu.pk

Syeda Maria Zafar
maria@scee.nust.edu.pk

[1] Department of Economics, Government College University Faisalabad, Faisalabad, Pakistan

[2] School of Economics, Quaid-i-Azam University, Islamabad, Pakistan

[3] Faculty of Economics and Administrative Sciences, Cag University, 33800 Mersin, Turkey

[4] Institute of Geographical Information System, School of Civil & Environmental Engineering, NUST, Islamabad, Pakistan

employment and improve living standards by making the economy better, and thus, it can lessen poverty in developing economies (Danish and Wang 2019). Furthermore, clean energy can enhance sustainable economic growth through improvements in agricultural, industrial, and service growths. It is therefore not surprising to see that these severe concerns over rising fossil fuel prices, macro-instability, energy security, and pollutant emissions have carried the significance of clean energy to the broader issue of the energy and environmental debate.

In past research, numerous studies debated that clean energy is the main engine for environmental quality in distinct countries of the globe by using various econometric tools, for example, Danish et al. (2017) for Pakistan, Katircioglu (2015) for Turkey, Dong et al. (2017) for China, Iwata et al. (2010) for France, Bilgili et al. (2016a, b) and Shahbaz et al. (2017) for the USA, Dogan and Seker (2016) for Europe, Bilgili et al. (2016a, b) for OECD, Sebri and Ben-Salha (2014) and Dogan and Inglesi-Lotz (2017) for BRICS countries, Zeb et al. (2014) for SAARC countries, Zoundi (2017) for African countries, and Solarin et al. (2018) for developing and developed countries. However, there has been a lot of studies to inspect the impacts of clean energy on carbon emissions in the globe. These research studies use only a linear model and mainly ignored the non-linear relationships among the clean energy and carbon dioxide emissions.

In sum, previous studies deliberated the impact of unclean energy consumption on carbon dioxide emissions of the globe. The link between unclean energy consumption and environmental degradation was observed very frequently in Pakistan. But there is limited work on the relation between clean energy consumption and CO_2 in Pakistan. Some empirical studies provide the association between clean energy and CO_2 that gives biased results because they used symmetric ARDL. For that reason, this study aims at fulfilling this gap by examining the asymmetric relationship among the consumption of clean energy and CO_2 in Pakistan by using data from 1975 to 2018 that has not been studied before. The foremost purpose of this study is to inspect the asymmetric impact of clean energy, i.e., nuclear and biomass on CO_2 in Pakistan. This study provides the effect of positive (or negative) shock of clean energy consumption on CO_2 in Pakistan. This study, compared with previous studies, has a parsimonious model. Additionally, this is the leading study on Pakistan and the globe that reflects asymmetric effects that provide a new framework in environmental economics. The results provide necessary economic implications for making the environment friendly to civilians, environmentalists, policymakers, researchers, and government authorities. This research is primarily essential within the framework of Pakistan's vision 2025 and 2035.

Next, the "Literature review" section gives a complete literature review and also provides a summary of the literature. "Methodology and data" shows the methodology, variable definition, and data descriptive statistics. "Results and discussion" gives the symmetric and asymmetric ARDL results of short and long run with economic implications. "Conclusion and policy implications" concludes the paper with some implications.

Literature review (Table 1)

The body of the literature relevant to the current study can be categorized into three sets. The first group aims to explore the empirical literature on renewable energy consumption and carbon emission nexus. A plethora of studies that explore the dynamic relationship between carbon dioxide emission and renewable energy consumption (REC) are accessible. The pertinent literature can be classified into panel data studies and time-series studies. Furthermore, the strand of panel data studies is twofold: firstly, the studies that deduce that the emission of carbon dioxide decreases on the account of using the REC, and secondly, the studies that support the positive association between carbon pollution. As for the first bunch, the majority of researches result in the negative association between REC and CO_2 emission. For instance, Apergis and Payne (2012), employing the panel ECM, explore that REC plays a significant role in decreasing the level of CO_2 emission in selected 80 economies in both short as well as long run. Similarly, Zeb et al. (2014) apply the FMOLS techniques and confirm that, in SAARC economies, the ratio of CO_2 emission faces the downfall as more renewable energy is consumed. Also, Sebri and Ben-Salha (2014) conclude the same findings in the case of BRICS economies.

Moreover, for using the Central American nation's studies, Apergis and Payne (2014) infer that, in the long run, REC mitigates the detrimental repercussions of CO_2 significantly after 2002 as compared with pre-2002. Likewise, for the European Union (EU) economies, the findings of the panel DOLS approach by Dogan and Seker (2016) confirm that REC and trade alleviate the harmful effects of toxic gases. The same result is also reported by Jebli et al. (2016) for selected 25 OECD economies, applying panel FMOLS method. Another study by Bilgili et al. (2016a, b) for selected 17 OECD countries employs panel FMOLS and DOLS approaches and supports the findings of Jebli et al. (2016). Besides, Bhattacharya et al. (2017) observed 85 developed and developing economies and deduce that the ratio of carbon dioxide significantly reduces due to consuming clean energy. Bhattacharya et al. (2016) also reported that government policymakers are increasing clean energy investment in 38 countries. Likewise, Paramati et al. (2017)

Table 1 Summary of literature

Author(s)	Country/region	Time span	Technique	Independent variables	Outcome
Panel A: renewable energy consumption and CO_2 emission					
Apergis and Payne (2012)	80 economies	1990–2007	Panel ECM	Renewable energy, GDP	↓
Apergis and Payne (2014)	7 central American economies	1980–2010	Panel ARDL	Renewable energy, coal price	↓
Jebli et al. (2016)	25 OECD economies	1980–2010	FMOLS	Renewable energy, trade openness, GDP	↓
Dogan and Seker (2016)	EU economies	1980–2012	Panel DOLS	Renewable energy, GDP	↓
Bilgili et al. (2016a, b)	OECD economies	1977–2010	FMOLS, panel DOLS	Renewable energy, GDP	↓
Dong et al. (2017)	5 BRICS economies	1985–2016	Panel VECM	Renewable energy, GDP	↓
Bhattacharya et al. (2017)	85 economies	1991–2012	FMOLS, GMM	Renewable energy, GDP	↓
Jebli and Youssef (2017)	5 North African economies		Panel ARDL	Renewable energy, GDP	↑
Paramati et al. (2017)	G20 economies	1991–2012	Panel Granger causality	Renewable energy, GDP	↓
Zoundi (2017)	25 African economies	1980–2012	Panel ARDL	Renewable energy, GDP	↓
Sebri and Ben-Salha (2014)	BRICS economies	1971–2010	Panel ARDL	Renewable energy, trade openness, GDP	↓
Lin and Moubarak (2014)	China	1977–2011	VECM	Renewable energy, GDP	×
Jaforullah and King (2015)	USA	1965–2012	ARDL	Renewable energy, energy price	↓
Danish et al. (2017)	Pakistan	1970–2012	VECM	Renewable energy, GDP	↓
Dong et al. (2018)	China	1965–2016	ARDL	Renewable energy, GDP	↓
Panel B: nuclear energy consumption and CO_2 emission					
Richmond and Kaufmann (2006)	Selected OECD and non-OECD	1973–1997	RE model	Nuclear energy, GDP	↓ for OECD × for non-OECD
Menyah and Wolde-Rufael (2010)	USA	1960–2007	VAR model	Nuclear energy, GDP	↓
Apergis et al. (2010)	19 economies	1984–2007	ECM Granger causality	Nuclear energy, GDP	×
Al-Mulali (2014)	30 major NUE-consuming economies	1990–2010	VECM	Nuclear energy, fossil fuels, GDP	×
Baek and Pride (2014)	Top 6 NUE-consuming economies	1965–2007	CVAR	Nuclear energy, GDP	×
Baek (2015)	12 major NUE-consuming economies	1980–2009	FMOLS, DOLS	Nuclear energy, GDP	↓
Saidi and Mbarek (2016)	9 developed economies	1990–2012	VECM	Nuclear energy, GDP	×
Ozturk (2017)	9 Latin American economies	1975–2013	VECM	Nuclear energy, GDP	×
Iwata et al. (2010)	France	1960–2003	ARDL	Nuclear energy, GDP	↓
Jaforullah and King (2015)	USA	1965–2012	VECM	Nuclear energy, energy price	×
Panel C: biomass energy consumption and CO_2 emission					
Katircioglu (2015)	Turkey	1980–2010	ARDL	Biomass energy, GDP	↓
Bilgili et al. (2016a, b)	USA	1984–2015	Wavelet coherence approach	Biomass energy, GDP	↓
Adewuyi and Awodumi (2017)	West Africa	1980–2010	3SLS	Biomass energy, coal energy, GDP	↑
Shahbaz et al. (2017)	USA	1960–2016	VECM	Biomass energy, trade openness	↓
Dogan and Inglesi-Lotz (2017)	BRICS economies	1985–2012	FMOLS	Biomass energy, trade openness, GDP	↓
Shahbaz et al. (2018)	G-7 economies	1980–2014	GMM	Biomass energy, FDI, GDP	↑
Solarin et al. (2018)	80 economies	1996–2016	GMM	Biomass energy, GDP	↑
Baležentis et al. (2019)	EU economies	1992–2015	FMOLD, DOLS	Biomass energy, trade openness, GDP	↓
Danish and Wang (2019)	BRICS economies	1992–2013	GMM	Biomass energy, trade openness, GDP	↓

↓, ↑, and × indicate the negative, positive, and no impact of the focused variable on carbon emission, respectively find out the same results for G-20 nations. Moreover, taking the data for 25 African economies, Zoundi (2017) explores the significantly negative nexus between the REC and CO_2 emission. Ahmed and Ahmed (2018) and Ahmed et al. (2019) revealed that REC remained significant in the pollution emission in the short and long run in developing countries. Shahbaz et al. (2015) have also advocated in favor of clean and green technologies in Australia. Ahmed and Ozturk (2018) shows that technical innovation increases clean energy intensity in China. A similar result is also found in the case of Malaysia by Shahbaz et al. (2016).

As far as the second bunch is concerned, Apergis et al. (2010), employing the panel ARDL technique, noted that REC effects the CO_2 in selected 19 developing and developed economies. In addition, taking the data for 5 North African economies, Jebli and Youssef (2017) also confirm that REC causes more CO_2 emission. As for the strand of time-series data studies, again, these are twofold. First is the studies that proclaim the negative nexus between REC and CO_2 emission. Jaforullah and King (2015), for the US economy, infer that, in both periods, REC creates a negative impact on the emission of CO_2. Likewise, Danish et al. (2017) also report the same results in the case of Pakistan. Secondly, two pieces of evidence indicate no significant connection between the production of carbon and REC, viz., Menyah and Wolde-Rufael (2010) for the USA, and Lin and Moubarak (2014) for China. Summing up, ample literature reveals the mix results regarding the effects of REC on CO_2 emission. Furthermore, there are only two studies, i.e., Zeb et al. (2014) for SAARC economies including Pakistan and Danish et al. (2017), which focused on Pakistan's economy.

While, the second group focuses on investigating nuclear energy consumption and CO_2 discharge nexus. Compared with the first bunch of studies, many researchers explore nuclear energy consumption (NEC) and the emission of CO_2 nexus. The available research can be categorized into panel data research and time-series research. As for the panel data studies, it can be further divided into two bunches. The first bunch contains the studies that support the argument that NEC significantly contributes to purifying the atmosphere by reducing the carbon dioxide emission. For instance, Richmond and Kaufmann (2006) deploy the random effect model and conclude that the trend of CO_2 falls due to NEC in the case of OECD economies. However, in the case of non-OECD economies, NEC exhibits no notable impact on the reduction of carbon dioxide emissions. Similarly, Apergis et al. (2010) demonstrate that, in the case of 19 developing and developed economies, NEC decreases the unfavorable environmental effects of CO_2 emission. Also, Baek (2015) reports that, in 12 primary nuclear energy—generating economies, the level of carbon dioxide emission declines as more of NE is utilized. While, the second bunch includes the studies that indicate the insignificant impact of NEC on the emission of CO_2, for example, Al-Mulali (2014) for 30 major NE-consuming economies, Baek and Pride (2014) for the top six nuclear energy–generating economies, Saidi and Mbarek (2016) for 9 selected developed nations, and Ozturk (2017) for 9 Latin American countries.

As far as the second group is concerned, employing the time-series data for France, Iwata et al. (2010) suggest that NEC promotes the decrease in the ratio of CO_2 emission. On the contrary, Jaforullah and King (2015) gather that NEC carries no significant dynamic association with carbon emissions in the USA. In short, the available relevant studies report the mix findings regarding the nexus of NEC and CO_2 emission. Besides, apparently, there is not a single study in the context of Pakistan that investigates the effects of NEC on the reduction in carbon dioxide. Further, the third group lists all the studies that report the biomass energy and carbon emission nexus. Researchers also explore the dynamic influence of biomass energy consumption (BEC) on carbon emission, and these studies can also be classified into two groups. The first group of scholars demonstrates that the role of BEC is significant in decreasing environmental stress by mitigating the emission of carbon dioxide. As Katircioglu (2015) applying the bound testing approach concludes, the trend of CO_2 emission faces downfall due to BEC in Turkey. Likewise, Bilgili et al. (2016a, b) infer that BEC mitigates the harmful effects of carbon dioxide on the environment in the USA. Another empirical study by Shahbaz et al. (2017) also reports the same findings for the USA.

Similarly, for BRICS economies, Dogan and Inglesi-Lotz (2017) confirm that BEC decreases the ratio of environmental pollution by reducing the emission of carbon dioxide. Besides, Baležentis et al. (2019) and Danish and Wang (2019) show that the level of CO_2 emission falls due to the environmental-friendly behavior of BEC for EU and BRICS economies, respectively. On the contrary, the second strand of scholars reveals the contradictive findings as compared with the first strand. For instance, Adewuyi and Awodumi (2017), deploying 3SLS technique, deduce that the adverse effects of CO_2 emission increase on the account of BEC in West Africa. Also, Solarin et al. (2018) gather that BEC affects environmental quality negatively by enhancing the emission of carbon dioxide in 80 developed and developing economies. Similarly, for G-7 economies, Shahbaz et al. (2018) conclude that the trend of environmental stress goes up due to an increase in CO_2 emission as more of biomass energy is consumed. Summarizing, again, the researchers present the scholarly disagreement regarding the BEC and CO_2 emission nexus as some of the scholars support the argument that BEC improves the environment quality by decreasing the emission of CO_2, while some other researchers disagree and report that environmental pollution increases on account of BEC. Further, there may not be a single study that explores the BEC and CO_2 emission nexus for Pakistan.

Methodology and data

Data and variable description

The present study has gathered data from WDI that covers the time period from 1975 to 2018. Regarding the dependent variable, CO_2 emission is used to proxy measured environmental quality, while two independent variables consist of clean energy. These comprise alternative and nuclear energy (% of total energy use) and combustible renewables and waste (metric tons of oil equivalent). Variables of electric power consumption (kilowatt-hour) and GDP are used as control variables. Electricity consumption includes all forms of energy whether clean and unclean. Moreover, these sets of energy variables are also being used together in the study of Maji (2015). All dependent and independent variables are retrieved from the WDI database. The data on dependent, independent, and control variables have been collected annually over the period 1975–2018 from WDI. We noted that data on some variables are available until 2014; however, we have extrapolated the data until 2018, to add few observations that will better serve the purpose in the case of our asymmetric model. Table 2 also gives the list of variable definition and measurement.

The mean of CO_2, ANE, CRW, EC, and GDP is 0.674 mt, 3.165%, 42.33 mt, 325.73 kWh, and 850.87, respectively, while the standard deviation is 0.189 mt, 0.491%, 8.838 mt, 129.89 kWh, and 165.02, respectively. The tendency of the variables, descriptive, and correlation statistics is offered in Table 3 and Fig. 1. Table 3 also shows the correlation matrix of the dependent and independent variables. The variables of ANE, EC, and GDP are positively correlated with CO_2, while the CRW is correlated with a negative manner on CO_2. In addition, EC and GDP are significantly negatively correlated to the RWC. Finally, there is also a significant positive relationship between EC and GDP.

Table 3 Summary statistics and correlation matrix

Variable	CO_2	ANE	CRW	EC	GDP
Descriptive statistics					
Mean	0.674	3.165	42.33	325.73	850.87
Std. dev.	0.187	0.491	8.838	129.89	165.02
Min	0.331	2.008	32.36	107.91	550.40
Max	0.946	4.032	60.43	538.82	1198.59
Correlation matrix					
CO_2	1				
ANE	0.097	1			
CRW	− 0.981*	− 0.037	1		
EC	0.967*	0.099	− 0.984*	1	
GDP	0.966*	0.172	− 0.950*	0.974*	1

Model and methodology

The main focus of this research is to estimate the impacts of different types of clean energy on CO_2 emission with special reference to Pakistan. To that end, we have selected two variables of clean energy: ANE and CRW. Hence, we have made the following simplest form of the model to analyze the connection between clean energy variables and CO_2 emission.

$$CO_{2,t} = \beta_0 + \beta_1 ANE_t + \beta_2 .CRW_t + \beta_3 EC_t + \beta_4 GDP_t + \mu_t \tag{1}$$

In Eq. (1), $CO_{2,t}$ is our dependent variable, which represents annual carbon dioxide release in Pakistan. Our independent variables in the above model include alternative and nuclear energy (ANE_t), combustible renewables and waste (CRW_t), electricity consumption (EC_t), and national income of Pakistan (GDP_t), and μ_t is the error term. However, the above model, with any method, would only give us long-run estimates. To get short-run estimates, as well, we have followed the methodology suggested by Pesaran et al. (2001) which is commonly identified as ARDL. In this methodology, we have restated model (1) by including error correction specification into it as given below:

Table 2 Variable description

Variables	Symbol	Definition	Data source
Carbon dioxide emissions	CO_2	CO_2 emissions (metric tons per capita)	WDI (2019)
Alternative and nuclear energy	ANE	Alternative and nuclear energy(% total energy use)	WDI (2019)
Combustible renewables and waste	CRW	Combustible renewables and waste (metric tons of oil equivalent)	WDI (2019)
Electric power consumption	EC	Electric power consumption(kwh)	WDI (2019)
GDP per capita	GDP	GDP per capita (constant 2010 US$)	WDI (2019)

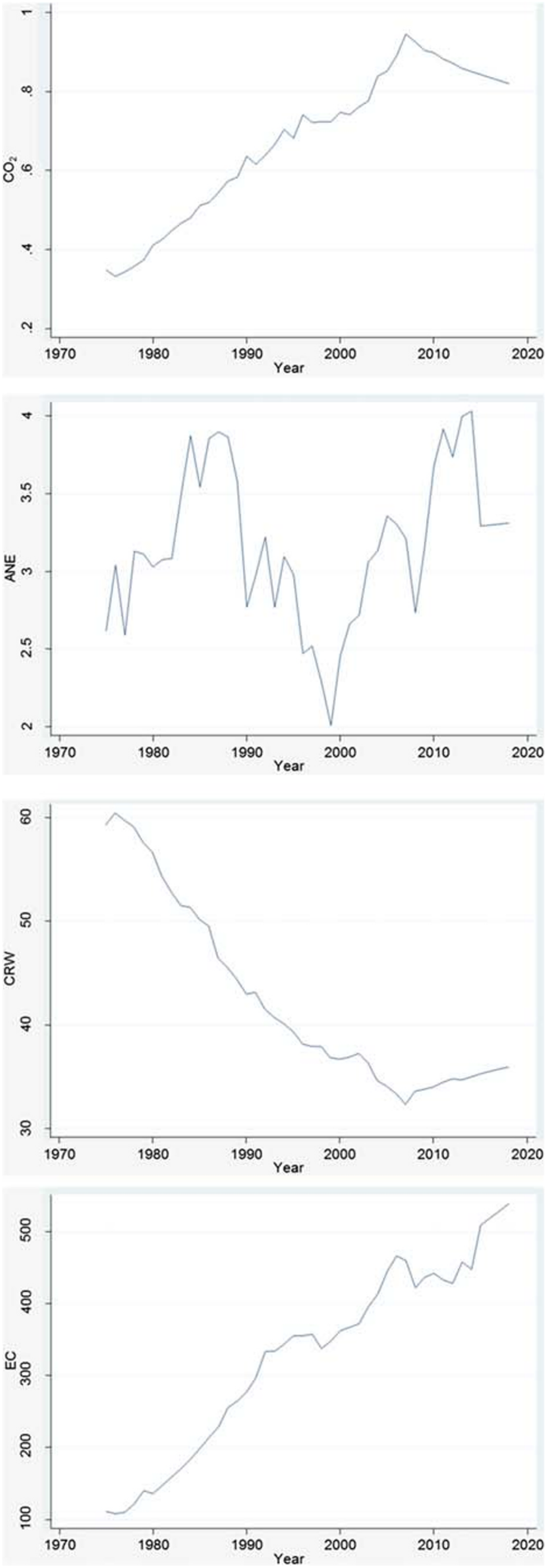

Fig. 1 Trend of the variables

$$\begin{aligned}\Delta CO_{2,t} = {} & \delta_0 + \sum_{n=0}^{p}\delta_1\Delta CO_{2,t-k} + \sum_{n=0}^{p}\delta_2\Delta ANE_{t-k} \\ & + \sum_{n=0}^{p}\delta_3\Delta CRW_{t-k} + \sum_{n=0}^{p}\delta_4\Delta EC_{t-k} \\ & + \sum_{n=0}^{p}\delta_5\Delta GDP_{t-k} + \pi_1 CO_{2,t-1} + \pi_2 ANE_{t-1} \\ & + \pi_3 .CRW_{t-1} + \pi_4 EC_{t-1} + \pi_5 GDP_{t-1} + \nu_t \end{aligned} \tag{2}$$

The main benefit of this technique over other approaches is that it helps us to estimate short-run as well as long-run parameters in a single equation. Moreover, as this method can also consider the integrating properties of the variables, we do not need to worry whether our variables are $I(0)$, $I(1)$, or mixture of both. In the above Eq. (2), the short-run results are depicted by those coefficients which are connected with differenced (Δ) indicators, whereas long-run results are represented by coefficients π_2–π_5 normalized on π_1. To get accurate long-run outcomes, we must need to check co-integration among long-run variables and for that purpose, we rely upon the values of bounds F-test presented by Pesaran et al. (2001). To detect the joint significance of long-run estimates, we will check whether the calculated value of bounds' test is large enough, i.e., larger than the values provided by Pesaran et al. (2001), or not; if calculated value is found to be higher than tabulated one, we can authorize the existence of co-integration. Though the values of bounds' F-test presented by Pesaran et al. (2001) are suitable for data sets that have a large number of observations, we have trusted the values of Narayan (2005) due to our small sample size. However, if the critical values of F-statistics are not significant, then we will move to the next test of co-integration which is identified as error correction modeling. As far as this technique is concerned, error term from Eq. (1) is corrected by the aid of normalized long-run estimates. Then, we substitute this error correction term (ECM_{t-1}) with the lagged level variables in Eq. (2). The new equation is then estimated by employing the same number of lags. In order to check the significance of $ECM_{t-1,}$ Pesaran et al. (2001) calculated new critical values of t test, just as they calculated critical values of F-test for joint significance of lagged level variables. If the value of ECM_{t-1} is significant and negative, then we can confirm the presence of co-integration.

Next, in this study, our primary target is to check whether the influence of clean energy variables on the CO_2 emission is symmetric or asymmetric. For that purpose, we follow the Shin et al. (2014) methodology of non-linear ARDL and we break down energy variables into their positive (POS) and negative (NEG) components by following partial sum procedure:

$$ANE^{+}{}_{t} = \sum_{L=1}^{t}\Delta ANE^{+}{}_{t} = \sum_{L=1}^{t}\max\left(\Delta ANE^{+}{}_{t}, 0\right) \tag{3a}$$

$$\mathrm{ANE}^{-}{}_{\mathrm{t}} = \textstyle\sum_{L=1}^{t} \Delta \mathrm{ANE}^{-}{}_{\mathrm{t}} = \sum_{L=1}^{t} \max(\Delta \mathrm{ANE}^{-}{}_{\mathrm{t}}, 0) \tag{4a}$$

$$\mathrm{CRW}^{+}{}_{\mathrm{t}} = \textstyle\sum_{L=1}^{t} \Delta \mathrm{CRW}^{+}{}_{\mathrm{t}} = \sum_{L=1}^{t} \max(\Delta \mathrm{CRW}^{+}{}_{\mathrm{t}}, 0) \tag{3b}$$

$$\mathrm{CRW}^{-}{}_{\mathrm{t}} = \textstyle\sum_{L=1}^{t} \Delta \mathrm{CRW}^{-}{}_{\mathrm{t}} = \sum_{L=1}^{t} \max(\Delta \mathrm{CRW}^{-}{}_{\mathrm{t}}, 0) \tag{4b}$$

$$\mathrm{EC}^{+}{}_{\mathrm{t}} = \textstyle\sum_{L=1}^{t} \Delta \mathrm{EC}^{+}{}_{\mathrm{t}} = \sum_{L=1}^{t} \max(\Delta \mathrm{EC}^{+}{}_{\mathrm{t}}, 0) \tag{3c}$$

$$\mathrm{EC}^{-}{}_{\mathrm{t}} = \textstyle\sum_{L=1}^{t} \Delta \mathrm{EC}^{-}{}_{\mathrm{t}} = \sum_{L=1}^{t} \max(\Delta \mathrm{EC}^{-}{}_{\mathrm{t}}, 0) \tag{4c}$$

Then, we entered these positive and negative shocks into linear ARDL model (2) as shown below:

$$\begin{aligned}\Delta \mathrm{CO}_{2,\mathrm{t}} = {} & \delta_0 + \textstyle\sum_{n=0}^{p} \delta_1 \Delta \mathrm{CO}_{2,\mathrm{t-k}} + \sum_{n=0}^{p} \delta_2 \mathrm{ANE}^{+}{}_{\mathrm{t-k}} \\ & + \textstyle\sum_{n=0}^{p} \delta_3 \mathrm{ANE}^{-}{}_{\mathrm{t-k}} + \sum_{n=0}^{p} \delta_4 \mathrm{CRW}^{+}{}_{\mathrm{t-k}} \\ & + \textstyle\sum_{n=0}^{p} \delta_5 \mathrm{CRW}^{-}{}_{\mathrm{t-k}} + \sum_{n=0}^{p} \delta_6 \mathrm{EC}^{+}{}_{\mathrm{t-k}} \\ & + \textstyle\sum_{n=0}^{p} \delta_7 \mathrm{EC}^{-}{}_{\mathrm{t-k}} + \sum_{n=0}^{p} \delta_6 \mathrm{EC}^{+}{}_{\mathrm{t-k}} \\ & + \textstyle\sum_{n=0}^{p} \delta_6 \mathrm{GDP}_{\mathrm{t-k}} + \pi_1 \mathrm{CO}_{2,\mathrm{t-1}} + \pi_2 \mathrm{ANE}^{+}{}_{\mathrm{t-1}} \\ & + \pi_3 \mathrm{ANE}^{-}{}_{\mathrm{t-1}} + \pi_4 \mathrm{CRW}^{+}{}_{\mathrm{t-1}} + \pi_5 \mathrm{CRW}^{-}{}_{\mathrm{t-1}} \\ & + \pi_6 \mathrm{EC}^{+}{}_{\mathrm{t-1}} + + \pi_7 \mathrm{EC}^{-}{}_{\mathrm{t-1}} + \pi_8 \mathrm{GDP}_{\mathrm{t-1}} + \nu_{\mathrm{t}}\end{aligned} \tag{5}$$

The above equation is recognized as non-linear ARDL model as proposed by Shin et al. (2014). Once we estimated the non-linear model (5), then we will move towards the test of asymmetries. First, we will check the short-run joint impact asymmetries ($\sum \delta_{2k} \neq \sum \delta_{3k}$, $\sum \delta_{4k} \neq \sum \delta_{5k}$, and $\sum \delta_{6k} \neq \sum \delta_{7k}$) by applying Wald test. If the cumulative sum of positive short-run shocks are not equal to the sum of negative shocks, we can indorse the occurrence of short-run asymmetry. Similarly, to check the long-run asymmetry (${}^{\pi_2^{+}}/_{\pi_1} \neq {}^{\pi_3^{-}}/_{\pi_1}, {}^{\pi_4^{+}}/_{\pi_1} \neq {}^{\pi_5^{-}}/_{\pi_1}, {}^{\pi_6^{+}}/_{\pi_1} \neq {}^{\pi_7^{-}}/_{\pi_1}$) we will also apply Wald test. If the impacts of normalized long-run positive shocks are unlike from the impacts of negative shocks, for each energy variable, then it is a confirmation of long-run asymmetry.

Results and discussion

In an ARDL specification, it does not matter whether the variables are non-stationary processes $I(1)$ or stationary processes $I(0)$. Therefore, we confirm the order of the integration of variables through Phillips and Perron (PP) and Augmented Dickey-Fuller (ADF) test. The results described in Table 4 show that both ADF and PP tests recommend that all the variables are integrated of order one, except CO_2 emissions variable.

In Table 5, using ARDL method, the long- and short-run coefficients in model 1 estimates are presented. The long- and short-run outcomes recommend that the coefficient of CRW is significant and inversely related to carbon emissions. While an adverse result is found in ANE and GDP, it has a significant positive influence on carbon emissions in the long run. Our primary focus, in clean energy and CO_2 emissions analysis, is on asymmetries. Therefore, in Table 5, we also examine the asymmetries in the nexus between clean energy and carbon emissions, both in short and long run. The outcomes specify that the estimate of the positive component of alternative and nuclear energy (ANE_t^{+}) is significant at 10% level and equal to 0.117 but the coefficient of the negative alternative and nuclear energy shock (ANE_t^{-}) is significant at 5% level and equal to 0.228. This indicates that in the long run the impact of alternative and nuclear energy on CO_2 is asymmetric, implying that the impact of positive shock of alternative and nuclear energy on CO_2 emission is different from that of negative alternative and nuclear energy shock. This implies that in short and long run, reductions in alternative and nuclear energy lead to an increase in non-renewable energy; non-renewable energy causes an increase in carbon emission in Pakistan and vice versa. Specifically, a 1% increase in alternative and nuclear energy leads to 0.117% increase in CO_2, but 1% decrease in alternative and nuclear energy leads to 0.228% increase in CO_2. It means that both positive and negative shocks are contributing to CO_2 emission in Pakistan. Nevertheless, the

Table 4 Unit root test

	ADF test statistic			PP test statistic		
	Level	First difference	Decision	Level	First difference	Decision
CO_2	4.043**	–	$I(0)$	2.732	6.468**	$I(1)$
	(0.003)			(0.076)	(0.000)	
ANE	2.436	3.521**	$I(1)$	2.513	7.456 **	$I(1)$
	(0.138)	(0.012)		(0.119)	(0.000)	
CRW	(2.604)	4.770 **	$I(1)$	2.267	4.984**	$I(1)$
	0.099	(0.000)		(0.186)	(0.000)	
EC	2.424	3.761**	$I(1)$	2.424	5.698**	$I(1)$
	(0.141)	(0.006)		(0.141)	(0.000)	
GDP	1.926	4.131**	$I(1)$	2.196	4.145**	$I(1)$
	(0.317)	(0.002)		(0.210)	(0.002)	

Table 5 Short-run and long-run estimates

Variables	ARDL results			NARDL results		
	Estimates	*T* ratio	*P* values	Estimates	*T* ratio	*P* values
Panel A: short-run estimates						
ΔANE_t	−0.009	0.217	(0.832)			
ΔANE_t^{+}				0.088**	1.997	(0.056)
ΔANE_t^{-}				0.177**	3.698	(0.000)
ΔANE_{t-1}^{-}				−0.105**	2.083	(0.046)
ΔCRW_t	−0.868**	4.791	(0.000)			
ΔCRW_t^{+}				−1.585**	3.499	(0.001)
ΔCRW_t^{-}				−0.851**	3.432	(0.001)
ΔEC_t	0.001	0.001	(0.986)			
ΔEC_t^{+}				−0.143	1.467	(0.153)
ΔEC_t^{-}				−0.418	1.592	(0.122)
ΔGDP_t	0.381	1.512	(0.140)	0.149	1.223	(0.231)
ECM_{t-1}	−0.565**	4.312	(0.001)	−0.759**	6.587	(0.000)
Panel B: long-run estimates						
ANE	0.151**	3.023	(0.004)			
ANE^{+}				0.117*	1.921	(0.650)
ANE^{-}				0.228**	5.852	(0.000)
CRW	−1.535**	7.453	(0.000)			
CRW^{+}				−2.088**	3.576	(0.001)
CRW^{-}				−1.120**	4.772	(0.000)
EC	0.138	1.457	(0.154)			
EC^{+}				0.082	0.691	(0.495)
EC^{-}				−0.071	0.208	(0.837)
GDP	0.111*	1.703	(0.097)	0.196	1.313	(0.267)
Constant	7.117**	3.669	(0.000)	−5.771	1.371	(0.018)
Panel C: diagnostic tests						
Bounds *F*-test	3.313			6.488**		
LM test	0.451	(0.501)		2.241	(0.134)	
Heteroskedasticity	10.38	(0.239)		16.98	(0.199)	
Jarque-Bera	3.203	(0.202)		0.452	(0.798)	
Ramsey RESET	0.600	(0.447)		0.041	(0.839)	
Adj-R^2	0.985			0.986		
WALD LR- ANE				0.027	(0.868)	
WALD SR- ANE				2.988*	(0.083)	
WALD LR- CRW				3.618**	(0.057)	
WALD SR- CRW				0.128	(0.719)	
WALD LR- EC				0.021	(0.870)	
WALD SR- EC				18.35**	(0.000)	

To check the significance, at 10% (5%) level, of our coefficient estimates, the tabulated value of *t* ratio is 1.64 (1.96).

The upper bound critical value of the *F*-test, at the 10% (5%) significance level, is − 3.89 (− 4.63).

As the LM, RESET and Wald tests are distributed at χ^2 with one degree of freedom. The critical values of all these tests are the same at 10% (5%) level of significance, i.e., 3.84 (2.70).

coefficient is small in magnitude; one possible reason is a relatively small share of ANE in the total energy mix in Pakistan that is 3.88%. According to Pakistan energy yearbook 2018, the energy share of contribution contains gas (29.02%), hydro (28.00%), thermal (21.91%), coal (12.44%), nuclear energy (3.88%), wind (3.59%), and solar (1.16%) (Hydrocarbon Development Institute of Pakistan 2018). The ANE is only a small share of total energy consumption and it increased very sluggishly, i.e., from 0.60% in 2010 to 3.88% in 2018. This finding is inconsistent with the work of Menyah and Wolde-Rufael (2010), Iwata et al. (2010), and Baek (2015), who suggested that nuclear energy helps to decrease CO_2 emission. This finding also indicates that the lack of facilities in nuclear energy consumption has largely increased the carbon emission, which enables the greenhouse gas problems and extensively disturbing the environments.

Similarly, in short run, the impact of alternative and nuclear energy use on CO_2 is also asymmetric. The estimated coefficient of the $\Delta \mathrm{ANE}_t^-$ shock is negative and equal to 0.117; this implies that in short run, decreases in ANE lead to an increase in carbon emissions. A 1% decrease in ANE causes a 0.117% increase in carbon emissions. This result also implies that positive shock is also bigger in the short run compared with a negative shock. However, the ANE coefficient is also negative significant in time period $(t-1)$, suggesting 1 year before ANE had a negative significant influence on carbon emissions.

Furthermore, concerning the effect of combustible renewables and waste energy on carbon emissions, the findings reveal the asymmetric effect both in the short and long run. In the long run, the impact of both positive and negative renewables and waste energy shocks is negative, implying that a 1% improvement in renewables and waste energy leads to 2.088% decrease in carbon emissions and 1% decrease in renewables and waste energy consumption leads to 1.120% decrease in carbon emissions. This also informs that positive combustible renewables and waste energy shock are stronger than negative shock on carbon emissions. Similarly, in the short run, both negative and positive renewables and waste energy shocks have reduced the carbon emissions. This finding is consistent with the findings of Katircioglu (2015), Bilgili et al. (2016a, b), and Danish and Wang (2019), who reported that renewables and waste energy deplete carbon emissions, while the empirical finding is inconsistent with Adewuyi and Awodumi (2017), who noted that combustible renewables and waste have a positive influence on carbon emission in West Africa. The possible reason is renewables and waste energy perform like a clean energy source, which assists in controlling pollution by reducing CO_2 emissions in Pakistan. The overall result focused on clean energy bases on the fact that the government is currently employing the legal structure for clean energy in Pakistan.

Estimation results further reveal that in the long run, the impact of electric power consumption on CO_2 emissions is insignificant while asymmetric in short run. The coefficient of the ECT is negative and significant verifying the long-run equilibrium relationships among competing variables. Particularly, the ECT coefficient is 0.565 in ARDL and 0.759 in NARDL, respectively. This indicates that the speeds of convergence are 56.5% and 75.9%, suggesting the high speed of adjustment in Pakistan.

Diagnostic test results are reported in panel C in Table 5. The optimal lag order was selected (0,1,0,0,0) in the ARDL model. After estimating the linear ARDL and non-linear ARDL models, the diagnostic tests were carried out to check the validity of the estimated models. However, heteroskedasticity test, serial correlation test, normality test, and functional form tests were used and the results revealed that they fail to reject the hypotheses of no heteroskedasticity, no serial correlation, normal residuals, and correct functional form in the ARDL and NARDL model. The diagnostic tests infer that ARDL and NARDL estimated are usable and do not have any inferential problem. In addition, adjusted R^2 is equal to 0.985 in ARDL and 0.986 in NARDL, indicating a good fit. Also, in asymmetric co-integration tested by using the F-test, the result confirmed that asymmetric co-integration exists in the short and long run. We have applied non-linear model because, in real-world scenario, symmetry in the effects of variables is hardly found. Moreover, literature does not suggest any of such tests that would be used to detect non-linearity in the data before applying NARDL. Few instances include studies like Apergis (2014), Cosmas et al. (2019), Karasoy (2019), and Awodumi and Adewuyi (2020); all these studies have checked the asymmetric impacts of different variables on environmental quality without the pre-estimation testing. The literature also suggests the post-estimation non-linearity test. Therefore, we have performed the Wald tests, after estimating our model, which confirms the existence of asymmetry in the effects of clean energy variables. In the case of nuclear energy and electricity consumption, Wald test confirms the presence of short-run impact asymmetries, in the effects of positive and negative parts of respective variables. As far as long-run asymmetry between positive and negative shocks is concerned, Wald test rejects it. On the other side, Wald test approves the non-linearity in the long-run positive and negative shocks of renewables and waste energy variable, whereas Wald test is insignificant in the case of short run.

Furthermore, we also performed CUSUM and CUSUMSQ tests to verify the stability of the parameters in the ARDL and NARDL model. However, the plot of CUSUM test in the ARDL model is unstable nevertheless. As far as this study is concerned, our primary objective is to check the asymmetry in the effects of clean energy variables. Therefore, this will not affect the validity of our non-linear results. Interestingly, the tests infer that computed NARDL model parameters are stable over the time period and the estimated model is reliable in Fig. 2.

Conclusion and policy implications

This study observes the asymmetries in the link between clean energy consumption and carbon dioxide emissions in Pakistan using the non-linear or asymmetric ARDL model approach for

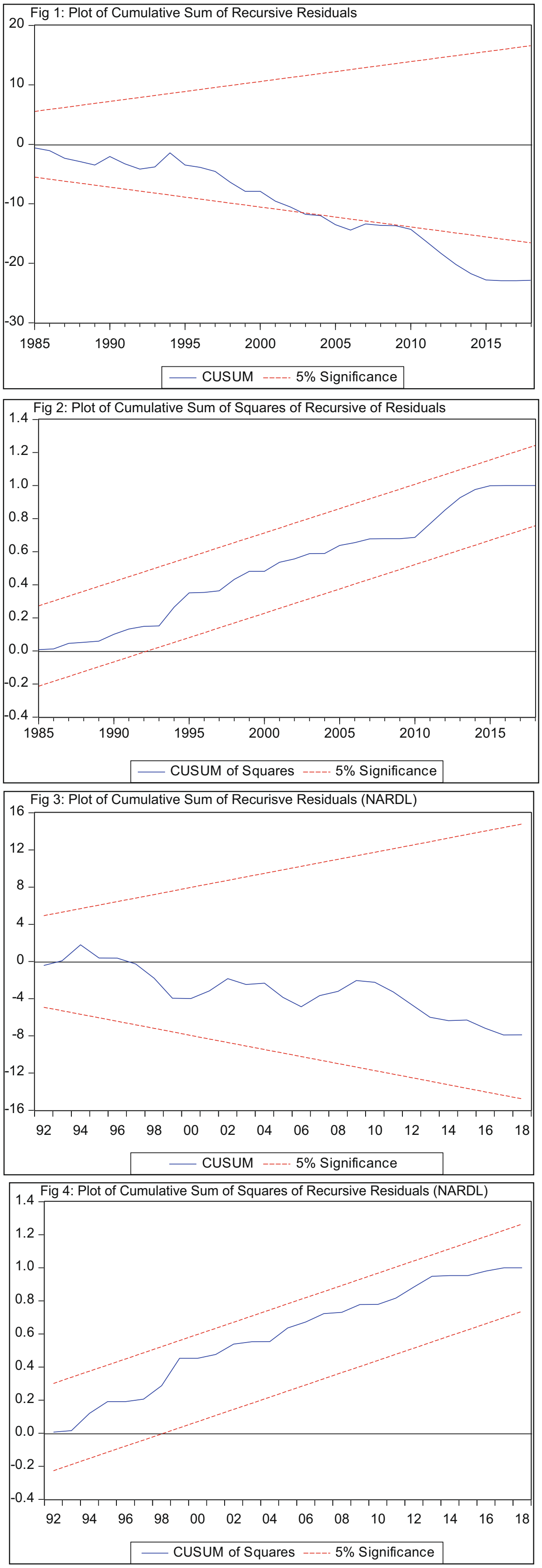

Fig. 2 The results of CUSUM test for the ARDL and NARDL model

the period of 1975–2018. The results from the estimated asymmetric ARDL model show that asymmetries exist in the relationships among ANE and carbon emissions in Pakistan, both in the short run and long run; the effect of negative shocks is dissimilar from that of positive shocks. Similarly, CRW affects carbon dioxide emissions, indicating that carbon dioxide emissions are affected by positive and negative energy shocks in the long run, while negative and positive energy shocks affect carbon dioxide emissions in the short run differently. Although short- and long-run results suggest an insignificant positive and negative relationship between electric power consumption and carbon emissions, the non-linear ARDL model results confirm that the asymmetry supposition can be supported in Pakistan. Indeed, asymmetric variations in clean energy are essential in the case of Pakistan, with estimated economic signs.

These empirical outcomes suggested that asymmetric cointegration exists in the model. This study is consistent with the study of Karasoy (2019), who noted that clean energy has an asymmetric effect on carbon emissions in Turkey. Overall, positive and negative shocks in ANE increase carbon emissions, whereas positive and negative changes in CRW consumption decrease carbon emissions in Pakistan. These results are valid and noticeable in Pakistan.

A rise in unclean energy consumption worsens the environment of Pakistan in long run, while an innovation of clean energy improves the environmental quality of Pakistan. The government should encourage clean energy for a healthier environment. Government and policymakers should give the long-run incentives and pursue the policies which would help to increase clean energy production in Pakistan. We urge that the governments of Pakistan should import new clean energy production technology. The government should take positive steps to change non-renewable energy to clean energy consumption that will not only reduce its energy dependency but also be a positive step towards combating global warming. Policymakers should pay more attention to public awareness about clean energy and its role in clean and green Pakistan. Regarding the limitation of the study, future research should examine the asymmetric effects of fossil fuel energy consumption on environmental pollution in Pakistan. Therefore, further empirical research in this area will appear fruitful in the policy context.

References

Adewuyi AO, Awodumi OB (2017) Biomass energy consumption, economic growth and carbon emissions: fresh evidence from West Africa using a simultaneous equation model. Energy 119:453–471

Ahmed K, Ahmed S (2018) A predictive analysis of CO 2 emissions, environmental policy stringency, and economic growth in China. Environ Sci Pollut Res 25(16):16091–16100

Ahmed K, Ozturk I (2018) What new technology means for the energy demand in China? A sustainable development perspective. Environ Sci Pollut Res 25(29):29766–29771

Ahmed K, Ozturk I, Ghumro IA, Mukesh P (2019) Effect of trade on ecological quality: a case of D-8 countries. Environ Sci Pollut Res 26(35):35935–35944

Al-Mulali U (2014) Investigating the impact of nuclear energy consumption on GDP growth and CO2 emission: a panel data analysis. Prog Nucl Energ 73:172–178

Apergis N (2014) Asymmetric real exchange rate pass-through and poverty in China: evidence from a nonlinear model. Appl Econ Lett 22(12):951–954

Apergis N, Payne JE (2012) Renewable and non-renewable energy consumption-growth nexus: evidence from a panel error correction model. Energy Econ 34(3):733–738

Apergis N, Payne JE (2014) Renewable energy, output, CO2 emissions, and fossil fuel prices in Central America: evidence from a nonlinear panel smooth transition vector error correction model. Energy Econ 42:226–232

Apergis N, Payne JE, Menyah K, Wolde-Rufael Y (2010) On the causal dynamics between emissions, nuclear energy, renewable energy, and economic growth. Ecol Econ 69(11):2255–2260

Awodumi OB, Adewuyi AO (2020) The role of non-renewable energy consumption in economic growth and carbon emission: evidence from oil producing economies in Africa. Energy Strateg Rev 27: 100434–100443

Baek J (2015) A panel cointegration analysis of CO2 emissions, nuclear energy and income in major nuclear generating countries. Appl Energy 145:133–138

Baek J, Pride D (2014) On the income–nuclear energy–CO2 emissions nexus revisited. Energy Econ 43:6–10

Baležentis T, Streimikiene D, Zhang T, Liobikiene G (2019) The role of bioenergy in greenhouse gas emission reduction in EU countries: an environmental Kuznets curve modelling. Resour Conserv Recy 142: 225–231

Bhattacharya M, Paramati SR, Ozturk I, Bhattacharya S (2016) The effect of renewable energy consumption on economic growth: evidence from top 38 countries. Appl Energy 162:733–741

Bhattacharya M, Churchill SA, Paramati SR (2017) The dynamic impact of renewable energy and institutions on economic output and CO2 emissions across regions. Renew Energy 111:157–167

Bilgili F, Koçak E, Bulut Ü (2016a) The dynamic impact of renewable energy consumption on CO2 emissions: a revisited environmental Kuznets curve approach. Renew Sust Energ Rev 54:838–845

Bilgili F, Öztürk İ, Koçak E, Bulut Ü, Pamuk Y, Muğaloğlu E, Bağlıtaş HH (2016b) The influence of biomass energy consumption on CO2 emissions: a wavelet coherence approach. Environ Sci Pollut Res 23(19):19043–19061

Cosmas NC, Chitedze I, Mourad KA (2019) An econometric analysis of the macroeconomic determinants of carbon dioxide emissions in Nigeria. Sci Total Environ 675:313–324

Danish, Wang Z (2019) Does biomass energy consumption help to control environmental pollution? Evidence from BRICS countries. Sci Total Environ 670:1075–1083

Danish, Zhang B, Wang B, Wang Z (2017) Role of renewable energy and non-renewable energy consumption on EKC: evidence from Pakistan. J Clean Prod 156:855–864

Dogan E, Inglesi-Lotz R (2017) Analyzing the effects of real income and biomass energy consumption on carbon dioxide (CO2) emissions: empirical evidence from the panel of biomass-consuming countries. Energy 138:721–727

Dogan E, Seker F (2016) Determinants of CO2 emissions in the European Union: the role of renewable and non-renewable energy. Renew Energy 94:429–439

Dong K, Sun R, Hochman G (2017) Do natural gas and renewable energy consumption lead to less CO2 emission? Empirical evidence from a panel of BRICS countries. Energy 141:1466–1478

Dong K, Sun R, Dong X (2018) CO2 emissions, natural gas and renewables, economic growth: assessing the evidence from China. Sci Total Environ 640:293–302

Georgescu M, Lobell DB, Field CB (2011) Direct climate effects of perennial bioenergy crops in the United States. Proc Natl Acad Sci 108(11):4307–4312

Hydrocarbon Development Institute of Pakistan (2018) Pakistan energy yearbook 2018. Hydrocarbon Development Institute of Pakistan, Ministry of Petroleum and Natural Resources, Government of Pakistan, Islamabad

Iwata H, Okada K, Samreth S (2010) Empirical study on the environmental Kuznets curve for CO2 in France: the role of nuclear energy. Energy Policy 38(8):4057–4063

Jaforullah M, King A (2015) Does the use of renewable energy sources mitigate CO2 emissions? A reassessment of the US evidence. Energy Econ 49:711–717

Jebli MB, Youssef SB (2017) The role of renewable energy and agriculture in reducing CO2 emissions: evidence for North Africa countries. Ecol Indic 74:295–301

Jebli MB, Youssef SB, Ozturk I (2016) Testing environmental Kuznets curve hypothesis: the role of renewable and non-renewable energy consumption and trade in OECD countries. Ecol Indic 60:824–831

Karasoy A (2019) Drivers of carbon emissions in Turkey: considering asymmetric impacts. Environ Sci Pollut Res 26(9):9219–9231

Katircioglu ST (2015) The impact of biomass consumption on CO2 emissions: an empirical investigation from Turkey. International Journal of Climate Change Strategies and Management 7(3):348–358

Lin B, Moubarak M (2014) Renewable energy consumption–economic growth nexus for China. Renew Sust Energ Rev 40:111–117

Maji IK (2015) Does clean energy contribute to economic growth? Evidence from Nigeria. Energy Rep 1:145–150

Menyah K, Wolde-Rufael Y (2010) CO2 emissions, nuclear energy, renewable energy and economic growth in the US. Energy Policy 38(6):2911–2915

Narayan PK (2005) The saving and investment nexus for China: evidence from cointegration tests. Appl Econ 37:1979–1990

Ozturk I (2017) Measuring the impact of alternative and nuclear energy consumption, carbon dioxide emissions and oil rents on specific growth factors in the panel of Latin American countries. Prog Nucl Energy 100:71–81

Paramati SR, Mo D, Gupta R (2017) The effects of stock market growth and renewable energy use on CO2 emissions: evidence from G20 countries. Energy Econ 66:360–371

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

Richmond AK, Kaufmann RK (2006) Is there a turning point in the relationship between income and energy use and/or carbon emissions? Ecol Econ 56(2):176–189

Saidi K, Mbarek MB (2016) Nuclear energy, renewable energy, CO2 emissions, and economic growth for nine developed countries: evidence from panel granger causality tests. Prog Nucl Energy 88:364–374

Sebri M, Ben-Salha O (2014) On the causal dynamics between economic growth, renewable energy consumption, CO2 emissions and trade openness: fresh evidence from BRICS countries. Renew Sust Energ Rev 39:14–23

Shahbaz M, Bhattacharya M, Ahmed K (2015) Growth-globalisation-emissions nexus: the role of population in Australia. Monash Business School Discussion Paper 23(15):1–33

Shahbaz M, Loganathan N, Muzaffar AT, Ahmed K, Jabran MA (2016) How urbanization affects CO2 emissions of STIRPAT model in Malaysia? The application. Renew Sust Energ Rev 57:83–93

Shahbaz M, Solarin SA, Hammoudeh S, Shahzad SJH (2017) Bounds testing approach to analyzing the environment Kuznets curve hypothesis with structural beaks: the role of biomass energy consumption in the United States. Energy Econ 68:548–565

Shahbaz M, Balsalobre D, Shahzad SJH (2018) The influencing factors of CO2 emissions and the role of biomass energy consumption: statistical experience from G-7 countries. Environ Model & Assess 24(2):143–161

Shin Y, Yu B, Greenwood-Nimmo M (2014) Modelling asymmetric cointegration and dynamic multipliers in a nonlinear ARDL framework. In: Festschrift in honor of Peter Schmidt. Springer, New York, pp 281–314

Solarin SA, Al-Mulali U, Gan GGG, Shahbaz M (2018) The impact of biomass energy consumption on pollution: evidence from 80 developed and developing countries. Environ Sci Pollut Res 25(23): 22641–22657

Ullah S, Ozturk I, Usman A, Majeed MT, Akhtar P (2020) On the asymmetric effects of premature deindustrialization on CO2 emissions: evidence from Pakistan. Environ Sci Pollut Res:1–11

Zeb R, Salar L, Awan U, Zaman K, Shahbaz M (2014) Causal links between renewable energy, environmental degradation and economic growth in selected SAARC countries: progress towards green economy. Renew Energy 71:123–132

Zoundi Z (2017) CO2 emissions, renewable energy and the environmental Kuznets curve, a panel cointegration approach. Renew Sust Energ Rev 72:1067–1075