**RESEARCH ARTICLE**

# Re-evaluating the asymmetric conventional energy and renewable energy consumption-economic growth nexus for Pakistan

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## Abstract
To understand the nexus between economic growth and energy sources, in this study, we have selected Pakistan and collected data over the period 1980–2016. The neoclassical production function of Pakistan is augmented with conventional and renewable energy, capital, and labor. Conversely, the conventional and renewable models are being constructed by using GDP as an independent variable. This paper applied linear and nonlinear ARDL models to see whether the influence of conventional and renewable energy consumption on GDP per capita of Pakistan is symmetric or asymmetric and vice versa. Furthermore, the asymmetric causal effects between the energy variables and economic growth are also discussed. From the findings of the study, we deduce the long-run asymmetric effects of renewable energy on the economic growth of Pakistan. Similarly, the asymmetric effects of GDP, in the long run, are confirmed in both energy models. The symmetric and asymmetric causality results have recommended growth and conservation hypothesis. The findings propose that renewable energy is a significant factor in boosting the economic growth of Pakistan and a decline in the use of renewable energy could actually stem the economic growth of Pakistan.

**Keywords** Conventional energy consumption · Renewable energy consumption · Economic growth · NARDL · Pakistan

## Introduction

Economic growth is going fast all over the world; however, most of the countries bear through shortage of energy power particularly in the production of electricity (Haas et al. 2011;

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Schmalensee 2012). Renewable energy consumption should be boosted, at least double, before 2030 to complement the development and to fulfill electricity demand (Alnaser and Alnaser 2011; Sen and Ganguly 2017). In this way, renewable energy consumption is appropriating an efficient choice in rising situations. Moreover, in developing and developed countries, renewable technologies are obtainable and consistent at even more economical prices (Verbruggen et al. 2010; Kannan and Vakeesan 2016). Now, it depends on the countries of the world to generate situations beneficial to accelerate renewable energy expansion to cover the means for unhindered sustainable development (Toumi and Toumi 2019).

All advanced nations attain energy by means of renewable and nonrenewable energy supplies (Pao and Fu 2013a, b; Pao et al. 2014). But, a sustainable development model that has swapped in support of conventional development model in recent times also diversifies the requirements of the countries for energy sources. Fossil fuels like oil, natural gas, and coal are the major energy sources in the traditional development model and have substituted renewable energy sources which are nuclear, wind, solar, geothermal energy, etc. in the sustainable development model (Bilgen et al. 2008; Panwar et al. 2011). These have a variety of externalities equally on nature

and economies. Whereas energy consumption is for a moment an aspect that distresses economic growth, it is also one contributing to environmental pollution, climate change, or global power wars. These harmful results enhance the significance of the investment in renewable energy sources that are the substitute for fossil fuels.

Renewable energy consumption provides less destruction to the environment (Schilling and Esmundo 2009). In order to diminish the destruction to the environment in the production of energy, many nations employ a few subsidies and incentives for renewable energy production (Frondel et al. 2010; Dincer 2011). For example, all European nations have undertaken the new EU renewable energy target. Therefore, the renewable energy share consumption in total energy consumption is intended to rise by 27 per cent until 2030 (Tuna and Tuna 2019).

It is notable to realize the level to which several kinds of energy consumption take part in the process of economic growth. The causalities among energy consumption and economic growth have various paths, to produce various policy suggestions (Ozturk 2010; Pao et al. 2014; Alper and Oguz 2016). One-way causal relationship through energy consumption to economic growth indicates the growth hypothesis which advocates adverse effects on economic growth in case of reduced consumption of energy (Balcilar et al. 2010; Binh 2011). Conversely, the one-sided causal association from economic growth to energy consumption highlights the fact that economic growth may not be adversely affected by consuming less energy and is known as "conservation hypothesis" (Tiwari 2011; Shahbaz et al. 2018). If the causal association does not exist among energy and growth, then it is recognized as neutrality hypothesis which implies as energy is not helpful in achieving economic growth in any way (Menegaki 2011a, b; Yıldırım et al. 2014). Lastly, there is a feedback effect which is indicative of two-sided causal link between energy and growth (Abalaba and Dada 2013).

According to 2010 International Energy Outlook announced through the United States Energy Information Administration (EIA) globally, renewable energy consumption has been enhancing by 2.6 per cent per year. During 2008, around 19 percent of the worldwide consumption of energy was as of renewable resources, conventional biomass (mostly used for heating) was 13 percent, 3.2 percent from hydroelectricity, and the left behind 2.7 percent through speedily rising new renewable such as small hydro, modern biomass, wind, solar, geothermal, and bio fuels. Renewable energy power creation builds around 18 percent of the worldwide electricity, by 15 percent through hydropower and 3 percent by further latest renewable energy resources. Latest renewable technologies are promoting for limited electricity production in rural and isolated regions, wherever the shipping prices for crude oil or natural gas and electricity diffusion costs are frequently prohibitively high. Internationally, three

million thousand are approximated to obtain power through small solar PV systems (Engerer 2014). In most of the regions, micro-hydropower systems organized into village-scale or county-scale mini-grids are rising. Above thirty million rural households utilize family-sized biogas digesters for lighting and cooking. Biomass cooking stoves have been utilized by one hundred and sixty million families (Fontani and Sansoni 2015).

In accordance with the 21st conference on climate change which was held in Paris in 2015, the green energy schemes regarding developing and developed nations aspire to exploit the production of energy capacity up to three hundred GW through the year 2030 as dealing severe hindrances narrated to the customary power improvement and decreasing the CO2 emissions (IEA 2015). The vision 2030 aim is to enhance renewable energy creation with a minimum of 9.5 GW. Renewable energy might comprise an essential ingredient of the electricity generation sector till 2030 by decreasing CO2 emissions and reducing the electricity production cost. Besides, in the previous twenty years, renewable energy consumption in the entire energy is raised and happens to be examined (Toumi and Toumi 2019).

Pakistan is an important country in South Asia with a population of 220 million people. The role of energy consumption in the economic growth of a developing country like Pakistan becomes more important. Pakistan fulfills its energy needs through various sources which include liquid fuels, coal, natural gas, hydropower, nuclear, etc. The largest chunk of energy consumption comes from the sources which are considered nonrenewable or conventional sources (liquid fuels, coal, and gas)[1], but the share of renewable resources is also, slowly but surely, on the rise. Hence, in the context of developing countries like Pakistan, it is very important to see the association between various energy sources and economic growth. This study contributes to the present literature in three ways: (1) it is using time series data which is free from the problem of aggregation bias as compared to panel data analysis; (2) it has targeted a country like Pakistan which is developing economy and used two diverse energy sources, i.e., conventional and renewable energy; (3) most importantly, besides symmetric analysis, the study has used the asymmetric analysis which is closer to real-world scenarios as each macroeconomic variable normally behaves asymmetrically. Asymmetry assumption based on the idea that if x% rise in an independent variable will raise the dependent variable by y%, then, x% decline in an independent variable may decrease or increase the dependent variable by more or may not have any significant effect at all.

This study is based on five different sections. In the next section, we have collected the latest literature on this topic. In the "Model, data, and methodology" section, we have

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discussed in detail the construction of models, data collection, and methodology. Then, in the "Empirical results" section, we have presented the results of our estimates, and finally, in the " Conclusion and implications" section, we have concluded the study and provided a few suggestions for policymakers.

## Literature review

Ozturk (2010) contributed to the energy consumption economic growth literature and electricity consumption economic growth causality relationship. It was concluded from the studies as causality among energy consumption and economic growth originated no consent on the continuation or direction of causality. A modified adaptation of the Granger causality analysis was applied by Wolde-Rufael (2010) from 1965 to 2005. The results showed one-directional causality successively through economic growth to coal consumption in South Korea and China. Besides, bidirectional causality was also investigated in South Africa and United States. Bowden and Payne (2010) investigated the fundamental link between renewable and nonrenewable energy consumption through sectors such as industrial, commercial, residential, and real GDP in the United States, and unpredictable results were found.

By applying ARDL bounds testing method of cointegration and VEC (vector error correction) models, Ozturk and Acaravci (2011) examined the short- as well as long-run causality among electricity consumption and economic growth through choosing eleven MENA (Middle East and North Africa) nations and observed no relationship among electricity consumption and economic growth in these MENA nations. Payne (2011) presented a disaggregated investigation of the causal association among fossil fuel (coal, natural gas, and petroleum) consumption and real GDP. The results concluded as various energy consumption substances have diverse impacts on real output. In a panel of twenty-seven European nations, Menegaki (2011a, b) initiated not any causality between renewable energy consumption and economic growth. Lately, renewable and nonrenewable energy consumptions are measured concurrently in the production model frame to distinguish the comparative influence of all types in the economic growth procedure.

Lee and Chiu (2011) examined one-directional long-run causality indication as of oil price and economic growth correspondingly to nuclear energy consumption, nor any short-run causality among nuclear energy consumption and economic growth, and alternatively among nuclear energy and oil for a panel of 6 vastly industrialized nations. The nexus relation between power and real GDP was investigated in Turkey by Kaplan et al. (2011) by the period of 1971 to 2006. The supposition of feedback was verified among both variables using ECM. Fang (2011) examined

the long-run association between renewable energy and economic well-being in China for the time ranging 1978 to 2008. Multivariate OLS regression results confirmed that renewable energy growth reinstated economic growth. Pao and Fu (2013a, b) inspected underlying association among clean and non-clean energy consumption and economic growth in Brazil comprising time span 1980–2009. The results showed an ambiguous relation among various clean energy kinds and economic growth.

To investigate the connecting linkage among renewable and nonrenewable energy consumption and economic growth, Pao et al. (2014) chose rising economies of the MIST (Mexico, Indonesia, South Korea, and Turkey) nations. Dedeoglu and Piskin (2014) observed the link among energy consumption and GDP/capita taking fifteen former Soviet Union nations above the time span between 1992 and 2009. The consequences support the existence of a one-directional underlying association successively by energy consumption to real GDP per capita in the long run, however, not in the short run. Moreover, the bidirectional link for oil importer and natural gas importer in the fifteen Soviet Union nations was also discovered. To explore the association among consumption of electricity, output, and price in the industrialized segment, Husaini and Lean (2015) took the case of Malaysia from 1978 to 2011 time span. A one-directional causality from industrialized output to the consumption of electricity in the long run was observed.

Through applying panel cointegration and causality techniques, it was suggested that MIST economies must be energy-dependent and that policies of energy management can decrease their economic development. Hamit-Haggar (2016) investigated the continuation and type of a causality association among clean energy consumption and economic growth selecting a panel of 11 SSA nations from 1971 to 2007. The results concluded co-integration between clean energy consumption and economic growth. Besides, unidirectional Granger causality arises from clean energy consumption to economic growth using panel causality tests. Jin and Kim (2015) investigated the underlying link among coal consumption and economic growth above the time span of 1971–2010 considering fifty-eight OECD and non-OECD nations. On the contrary, the long-run association has not existed among coal consumption and economic growth in the case of non-OECD counties.

The link between renewable energy consumption and economic growth was investigated by Shahbaz et al. (2015) through the use of quarterly data above the time span of 1972q1–2011q4 and through including capital and labor as prospective production function determinants in Pakistani context. The two-directional causality among economic growth and renewable energy consumption was found from their results. Bento and Moutinho (2016) verified the presence of causal relationships among $CO_2$ emissions, renewable

electricity production, and real GDP in Italy for the period more than 1960 to 2011. The panel cointegration method by applying an ARDL model showed negative association among per capita renewable electricity production on carbon dioxide equally in short- as well as long-run associations. Additionally, the Granger causality method indicated one-directional link successively by the output to renewable electricity in the long run. The casual relationship between economic growth, energy consumption, financial development, trade openness, and CO2 emissions was examined through Rafindadi (2016). The data was taken for the period of 1971 to 2011. The ARDL bounds testing method through the Granger causality method showed that financial development improves the use of energy and enhances CO2 emissions. Moreover, the deviation in policy suggestions has also shown in the context of Nigeria. Similarly, Yang et al. (2020) confirmed the bidirectional causality between the financial development indicators and energy consumption in the selected Asian economies.

Jebli and Belloumi (2017) observed the underlying association among carbon emissions, GDP growth, and explosive renewable energy in Tunisia for the period of 1980 to 2011. By applying ARDL model, one-directional causal relation was created from real GDP and renewable energy to $CO_2$ emissions. The asymmetric link among energy consumption and economic growth along with financial development, capital, and labor into a production function was inspected through Shahbaz et al. (2017) from 1960Q1 to 2015Q4 selecting the Indian economy. The co-integration among the variables in the occurrence of asymmetries was found. It was also observed that just negative shocks to energy consumption have an impact on economic growth. Paramati et al. (2017) tried to analyze the importance of renewable energy for economic production ranging 1990–2012 as investigating developing nations. The link among the variables was confirmatory and has negatively damaged carbon dioxide emissions by employing a heterogeneous non-causality method. A novel idea was proposed by Zhu et al. (2018) and the relationship between the economic crisis and the European carbon market has been observed. The findings of the study confirmed the negative effects of both the financial crisis and the European debt crisis on the carbon market in Europe. Lu et al. (2019) analyzed the determinants of aquifer thermal energy storage (ATES) and the potential of ATES particularly in the presence of socioeconomic, geo-hydrologic, and climatic conditions. The study confirmed that ATES has a potential in the regions of Asia and North America. Moreover, the large portions of ATES hotspots are situated in western Europe. Usman et al. (2020) found asymmetries in the effects of renewable energy consumption on the CO2 emissions in Pakistan both in short run and long run by applying NARDL model. The study

further elaborated that more taxation should be imposed on nonrenewable energy sources, while subsidies should be granted in the projects of clean energy which would have a positive impact on the environmental quality in Pakistan. Likewise, Sun et al. (2020) specified that inequalities in energy consumption in the countries of one belt one road (OBOR) negatively impacted the environmental quality, in the long run, except the countries of South Asia and Southeast Asia. They also confirmed that financial development also hurt the environmental quality in the entire region except for East Asia.

By taking the case of ASEAN-5 nations, Tuna and Tuna (2019) evaluated causality among energy consumption and economic growth for the time span of 1980–2015. It was recommended that, by applying Hacker and Hatemi-J (2006) tests for symmetric causality and Hatemi-J (2012) for asymmetric causality, economic growth and renewable energy consumption are not usually linked to growth of ASEAN-5 nations. Moreover, the occurrence of a significant association among nonrenewable energy consumption and economic growth was also suggested. Toumi and Toumi (2019) employed asymmetric causality to renewable energy (REC), carbon dioxide emissions (CE), and real GDP applying nonlinear dissemination among these variables by the NARDL model to investigate the short- and long-run asymmetries in the variation of greenhouse gas emissions between variables and to take out the asymmetric underlying chosen variables via positive and negative shocks for time series data through the Kingdom of Saudi Arabia from 1990 to 2014. It was observed that negative shocks in CE had just positive influences on real GDP in the long run but are unobservable in the short run. The asymmetric causal association from CE to REC is unbiased in the long run.

## Model, data, and methodology

### Model

The relationship between economic growth and energy consumption has become a focal point for many researchers. Therefore, lately, many studies have attempted to capture the causal link between economic growth and energy consumption. In the present study, we want to see this relationship from a different perspective, i.e., whether the nexus between them is symmetric or asymmetric. However, we need to develop the basic models which could capture the impact of energy consumption on economic growth and vice versa. Firstly, we will see the construction of growth models of Pakistan used in this study and then we will turn our attention to energy models.

The starting point of most of the studies, in the development of a growth model, is Cobb-Douglas production function with the inclusion of labor and capital. Researchers like Pao and Fu (2013a, b), Maji (2015), Apergis and Payne (2010a, b, c, Apergis and Payne 2012), and Al-Mulali et al. (2014) entered a different type of energy variables on the right-hand side of the production function. Following, these researchers have included two kinds of energy resources in our growth model, viz., conventional energy consumption (energy consumption from all nonrenewable sources such as coal, natural gas, and liquid fuels) and renewable energy (energy consumption from nuclear and other renewable sources) consumption. Hence, to achieve our objective, we have constructed two separate growth models, one with an independent variable of conventional energy and the other with renewable energy. The functional forms of these models are given below:

$$GDP_t = f\ (\ GFC_t, LF_t, CE_t) \tag{1a}$$

$$GDP_t = f\ (\ GFC_t, LF_t, RE_t) \tag{1b}$$

To convert these functional forms into econometric models, we have added intercept term, slope parameter beside each variable, and normally distributed error term on the right-hand side of Eq. 1a and 1b. Then, we have also converted these econometric models into natural log forms as stated in Eq. 2a and 2b:

$$Ln\ GDP_t = \alpha + \beta\ LnGFC_t + \gamma\ LnLF_t + \delta\ LnCE_t + \mu_t \tag{2a}$$

$$Ln\ GDP_t = \alpha_1 + \beta_1 LnGFC_t + \gamma_1 LnLF_t + \delta_1 LnRE_t + \mu_t \tag{2b}$$

In the above equation (2a & 2b), $GDP_t$ represents GDP per capita of Pakistan; $GFC_t$ represents the gross fixed capital stock in constant \$US; $LF_t$ represents the total labor force of Pakistan; $\mu_t$ is the error term which is normally distributed. However, in Eq. (2a), $CE_t$ symbolizes the conventional or nonrenewable energy and in Eq. (2b), $RE_t$ indicates renewable energy. The subscript $t$ with each variable portrays that data is varying across time.

Then, following Ozturk and Acaravci (2010), to see the impact of economic growth on energy consumption, we have constructed two more models. One model is referred to as a conventional energy model and the other model is called a renewable energy model; however, the independent variable for both the energy models remains the same, i.e., GDP per capita of Pakistan. Consequently, the energy models take the following forms:

$$CE_t = f\ (GDP_t) \tag{3a}$$

$$RE = f\ (GDP_t) \tag{3b}$$

The econometric models of Eq. 3a and 3b in the form of a natural log are expressed below in Eq. 4a and 4b:

$$Ln\ CE_t = a + b\ LnGDP_t + \mu_t \text{————} \tag{4a}$$

$$Ln\ RE_t = a_1 + b_1\ LnGDP_t + \mu_t \tag{4b}$$

## Methodology

Given the fact that none of our variables is I (2), hence, we can apply the ARDL methodology proposed by Pesaran et al. (2001). For that, we need to present Eqs. 2a, 2b, 4a, and 4b into error correction specification as shown below:

$$\Delta Ln\ GDP_t = \alpha_0 + \sum_{i=1}^{n1} \alpha_1 \Delta LnGDP_{t-i}$$

$$+ \sum_{i=0}^{n2} \alpha_2 \Delta LnGFC_{t-i} + \sum_{i=0}^{n3} \alpha_3 \Delta LnLF_{t-i}$$

$$+ \sum_{i=0}^{n4} \alpha_4 \Delta LnCE_{t-i} + \eta_1 LnGDP_{t-1}$$

$$+ \eta_2 LnGFC_{t-1} + \eta_3 LnLF_{t-1}$$

$$+ \eta_4 LnCE_{t-1} + \mu_t \tag{5a}$$

$$\Delta Ln\ GDP_t = \beta_0 + \sum_{i=1}^{n1} \beta_1 \Delta LnGDP_{t-i}$$

$$+ \sum_{i=0}^{n2} \beta_2 \Delta LnGFC_{t-i} + \sum_{i=0}^{n3} \beta_3 \Delta LnLF_{t-i}$$

$$+ \sum_{i=0}^{n4} \beta_4 \Delta LnRE_{t-i} + \pi_1 LnGDP_{t-1}$$

$$+ \pi_2 LnGFC_{t-1} + \pi_3 LnLF_{t-1}$$

$$+ \pi_4 LnRE_{t-1} + \mu_t \tag{5b}$$

$$\Delta Ln\ CE_t = a_0 + \sum_{i=1}^{n1} a_1 \Delta LnCE_{t-i} + \sum_{i=0}^{n2} a_2 \Delta LnGDP_{t-i}$$

$$+ \theta_1 LnCE_{t-1} + \theta_2 LnGDP_{t-1} + \mu_t \tag{6a}$$

$$\Delta Ln\ RE_t = b_0 + \sum_{i=1}^{n1} b_1 \Delta LnRE_{t-i} + \sum_{i=0}^{n2} b_2 \Delta Ln\ Y_{t-i}$$

$$+ \phi_1 LnCE_{t-1} + \phi_2 LnGDP_{t-1} + \mu_t \tag{6b}$$

The above equations (5a, 5b, 6a, 6b) are known as ARDL models. This methodology has few advantages over other methodologies: firstly, it can give short-run and long-run estimates by the help of single equation; secondly, it can account for the integrating properties of variables which means we can either use variables of I(0) or I(1) or a combination of both; thirdly, it works well even in the case of small samples.

Next, to achieve our foremost objective of capturing the asymmetric impact of two energy sources on the economic growth of Pakistan and vice versa, we have disintegrated our two energy variables and GDP variable into their positive ($CE\_POS_t^+$, $RE\_POS_t^+$, $GDP\_POS_t^+$) and negative ($CE\_NEG_t^-$, $RE\_NEG_t^-$, $GDP\_NEG_t^-$) components by using partial sum procedure proposed by Shin et al. (2014). The process of breaking down of variables by using partial sum procedure is as follows.

$$CE\_POS_t^+ = \sum_{m=1}^{t} \max\left(\Delta LnCE_m^+, 0\right) \text{ and} CE\_NEG_t^-$$

$$= \sum_{j=1}^{t} \min\left(\Delta LnCE_m^-, 0\right) \qquad (7a)$$

$$RE\_POS_t^+ = \sum_{m=1}^{t} \max\left(\Delta LnRE_m^+, 0\right) \text{ and} RE\_NEG_t^-$$

$$= \sum_{j=1}^{t} \min\left(\Delta LnRE_m^-, 0\right) \qquad (7b)$$

$$GDP\_POS_t^+ = \sum_{m=1}^{t} \max\left(\Delta LnY_m^+, 0\right) \text{ and } GDP\_NEG_t^-$$

$$= \sum_{j=1}^{t} \min\left(\Delta LnGDP_m^-, 0\right) \qquad (7c)$$

Now we will replace these positive and negative components of variables into Eqs. 5a, 5b, 6a, and 6b:

$$\Delta Ln\, GDP_t = \alpha_0 + \sum_{i=1}^{n1} \alpha_1 \Delta LnGDP_{t-i}$$

$$+ \sum_{i=0}^{n2} \alpha_2 \Delta LnGFC_{t-i} + \sum_{i=0}^{n3} \alpha_3 \Delta LnLF_{t-i}$$

$$+ \sum_{i=0}^{n4} \alpha_4 \Delta LnPCE_{t-i}^+ + \sum_{i=0}^{n5} \alpha_5 \Delta LnNCE_{t-i}^-$$

$$+ \eta_1 LnGDP_{t-1} + \eta_2 LnGFC_{t-1}$$

$$+ \eta_3 LnLF_{t-1} + \eta_4 LnPCE_{t-1}^+$$

$$+ \eta_5 LnNCE_{t-1}^- + \mu_t \qquad (8a)$$

$$\Delta Ln\, GDP_t = \beta_0 + \sum_{i=1}^{n1} \beta_1 \Delta LnGDP_{t-i}$$

$$+ \sum_{i=0}^{n2} \beta_2 \Delta LnGFC_{t-i} + \sum_{i=0}^{n3} \beta_3 \Delta LnLF_{t-i}$$

$$+ \sum_{i=0}^{n4} \beta_4 \Delta LnRE\_POS_{t-i}^+$$

$$+ \sum_{i=0}^{n5} \beta_5 \Delta LnRE\_NEG_{t-i}^- + \pi_1 LnGDP_{t-1}$$

$$+ \pi_2 LnGFC_{t-1} + \pi_3 LnLF_{t-1}$$

$$+ \pi_4 LnRE\_POS_{t-1}^+ + \pi_4 LnRE\_NEG_{t-1}^-$$

$$+ \mu_t \qquad (8b)$$

$$\Delta Ln\, CE_t = a_0 + \sum_{i=1}^{n1} a_1 \Delta LnCE_{t-i}$$

$$+ \sum_{i=0}^{n2} a_2 \Delta LnGDP\_POS_{t-i}^+$$

$$+ \sum_{i=0}^{n2} a_3 \Delta LnGDP\_NEG_{t-i}^- + \theta_1 LnCE_{t-1}$$

$$+ \theta_2 LnGDP\_POS_{t-1}^+ + \theta_3 LnGDP\_NEG_{t-1}^-$$

$$+ \mu_t \qquad (9a)$$

$$\Delta Ln\, RE_t = b_0 + \sum_{i=1}^{n1} b_1 \Delta LnRE_{t-i}$$

$$+ \sum_{i=0}^{n2} b_2 LnGDP\_POS_{t-i}^+$$

$$+ \sum_{i=0}^{n2} b_3 LnGD\_NEG_{t-i}^- + \phi_1 LnCE_{t-1}$$

$$+ \phi_2 LnGDP\_POS_{t-i}^+ + \phi_3 LnGDP\_NEG_{t-i}^-$$

$$+ \mu_t \qquad (9b)$$

Equations 8a, 8b, 9a, and 9b are known as nonlinear or asymmetric ARDL forwarded by Shin et al. (2014). These models are similar to linear ARDL models, except, we have replaced energy and GDP variables with their positive and negative parts. Hence, the bounds F-test proposed by Pesaran et al. (2001), to confirm the combined significance of lagged-level variables, is equally applicable in case of NARDL. On the other hand, one extra thing we need to deal with in case of NARDL is tests of asymmetries equally in the short run and long run. In the short run, we have three different types of asymmetry tests. First, we need to see whether the number lags attached to $\Delta CE\_POS^+$, $\Delta RE\_POS^+$, and $\Delta GDP\_POS^+$ are different from the lag length attached to $\Delta CE\_NEG^-$, $\Delta RE\_NEG^-$, and $\Delta GDP\_NEG^-$, respectively, and, if they prove to be different, then this is an indication of adjustment asymmetry. Next, we examine the coefficient estimates associated with our positive shocks ($\Delta CE\_POS^+$, $\Delta RE\_POS^+$, and $\Delta GDP\_POS^+$) and if they contrast, in terms of sign and size, from our negative shocks ($\Delta CE\_NEG^-$, $\Delta RE\_NEG^-$, and $\Delta GDP\_NEG^-$), this confirms short-run individual asymmetry. Lastly, the proof of short-run impact asymmetry is found in Models 8a, 8b, 9a, and 9b if we successfully reject the null hypothesis of short-run Wald test, i.e., $\sum \alpha_4 = \sum \alpha_5$, $\sum \beta_4 = \sum \beta_5$, $\sum a_2 = \sum a_3 \& \sum b_2 = \sum b_3$ individually. As for the long-run asymmetry is concerned, we performed the long-run Wald test and, once again rebuffing the null hypothesis $\frac{\eta_4}{-\eta_1} = \frac{\eta_5}{-\eta_1}$ in Eq. 8a, $\frac{\pi_4}{-\pi_1} = \frac{\pi_5}{-\pi_1}$ in Eq. 8b, $\frac{\theta_2}{-\theta_1} = \frac{\theta_5}{-\theta_1}$ in Eq. 9a and $\frac{\phi_2}{-\phi_1} = \frac{\phi_3}{-\phi_1}$ will prove the asymmetric effects of independent variables on dependent ones in their corresponding equations.

## Data

We have selected Pakistan as our study area and collected data over the period 1980–2016. Data on renewable (energy obtained from nuclear and other clean sources) and conventional (sum of all energy consumption obtained from sources like liquid fuels, natural gas, and coal) energy comes from Energy Information Administration (EIA)[2]. Data on GDP per capita, gross fixed capital formation (constant 2010 US$), and total labor force come from the World Development Indicators (WDI). Few missing values in the data have been generated with the help of linear extrapolation.

## Stationary tests

Though the macroeconomic series mostly become stationary even at the first difference, hence, the unit root tests are not a pre-requisite for most commonly used time series methodology of bounds testing approach to co-integration and error correction modeling. However, we want to confirm that none of our included variables is non-stationary even after a first difference; in other words, no variable should be I(2). To that end, we applied Augmented Dickey-Fuller (ADF) and Phillips Peron (PP) unit root tests which confirm the fact as all our variables are either stationary at a level or 1st difference. Moreover, Zivot and Andrews (ZA) (1992) unit root test is also performed to accommodate any structural break in the data series, the results of which are quite similar to the stationary tests without a structural break.

## Empirical results

In this section, we estimate production and energy models by using the symmetric ARDL and asymmetric ARDL methodology by employing the annual time series dataset over the period 1980–2016. As a pilot test, since the ARDL approaches require the variables to be a combination of I(0) and I(1), we test for these initial properties and show the results of ADF and PP unit root statistics in Table 1. From Table 1, GDP, GFC, LF, CE, and RE are stationary at I(1) in ADF, while the PP unit root statistics are also given in Table 1.

Table 2 reports the short and long estimates of ARDL and NARDL model by examining the conventional energy (CE) and renewable energy (RE) consumption impacts on GDP per capita (Y) in Pakistan. In ARDL estimates in short run, CE has a positive impact on GDP per capita while this impact is insignificant in the long run on GDP per capita. The result is reliable with earlier empirical studies of Magazzino (2014). This implies that conventional energy is a basic source of

economic activities and has a significant positive influence on GDP per capita. However, an increase in conventional energy stimulates GDP per capita and is considered one of the proficient instruments to increase GDP in short run in Pakistan. Another reason is conventional energy improves the macroeconomic efficiency of economies in developing economies as well as in Pakistan. In the long run, RE has a statistically significant influence on GDP per capita, whereas in the short run, results are insignificant in Pakistan. This shows that renewable energy brings output improvement and, as result, enhances GDP per capita in the long run. This result is similar to that of Amri (2017) in Algeria's study. Similarly, GFC and labor force have also a positive effect on GDP per capita in the long run, while this effect is insignificant on GDP per capita in the early two models.

In asymmetric estimates, how NARDL estimates are deviated in the long and short run from the ARDL. The results show that positive shock in CE has a positive impact on GDP per capita in the short run while negative shock exerts a negative insignificant effect on GDP. Long-run results show that positive and negative shock in CE has also an insignificant effect on GDP per capita in the long run. These results imply the fact that Pakistan is already consuming the conventional energy up to its full potential; hence, any shock, whether positive or negative, in conventional energy sources will not have any impact on the economic prosperity of people.

Moreover, the coefficient of the positive shock of RE has a positive and significant effect on GDP per capita in Pakistan in the long run, whereas the coefficient of negative shock has a negative and significant impact. However, the short-run estimates, whether attached to positive or negative shocks, are insignificant. Correspondingly, the coefficient of LF and GFC has a positive effect on GDP per capita in Pakistan and results are also maintained in the NARDL model. The coefficient of error correction term found a negative sign with statistical significance at 5% levels of significance in the last two symmetric and asymmetric models. This has confirmed the continuation of long-run connections among CE and GDP per capita in Pakistan.

Linear and nonlinear ARDL model also shows the few diagnostic statistics in Table 3 in Panel C. To check for autocorrelation and misspecification problems, we have applied the Lagrange multiplier (LM) and Ramsey's RESET tests in all models. All statistics in four models are also insignificant, which implies that there are no problems of autocorrelation and the model is correctly specified. The statistics of F-test and ECM or $t$ test has a significance, which evidence of co-integration existed in both models. These findings also show that the deviation of variables from the short-run to the long-run equilibrium is balanced by 21.4%, 35.0 %, 48.8%, and 64.5% per year in linear and nonlinear models. We also have tested for the stability of parameters by using the CUSUM and CUSUM squares tests to the residuals, which indicates the

**Table 1** Unit root tests

|  | LNGDP | LNGFC | LNLF | LNCE | LNRE |
|---|---|---|---|---|---|
| *ADF* |  |  |  |  |  |
| I(0) | −0.721 | −1.567 | −0.356 | −1.980 | −1.925 |
| I(1) | −3.755*** | −4.362*** | −6.269*** | −5.123*** | −5.889*** |
| Decision | I(1) | I(1) | I(1) | I(1) | I(1) |
| *PP* |  |  |  |  |  |
| I(0) | −1.447 | −1.567 | −0.453 | −3.512** | −1.951 |
| I(1) | −3.753*** | −4.394*** | −6.261*** |  | −5.888*** |
| Decision | I(1) | I(1) | I(1) | I(0) | I(1) |
| *ZA* |  |  |  |  |  |
| I(0) | −2.023 | −1.025 | −2.014 | −4.356*** | −2.135 |
| Break year | 2011 | 2001 | 2006 | 1999 | 2006 |
| I(1) | −8.003*** | −4.987*** | −6.355*** |  | −6.564*** |
| Break year | 2008 | 1998 | 2002 |  | 2003 |

steady estimates by representing as "S," in linear ARDL and nonlinear ARDL models. Finally the adjusted R-square also shows the goodness of fit in both linear and nonlinear models.

In ARDL, Table 3 indicates that coefficients of GDP have a positive and significant effect on CE and RE in the short run, whereas GDP has also a significant impact on CE and RE in the long run, respectively. Furthermore, long-run elasticity of GDP has a higher magnitude than short-run elasticity in symmetric ARDL. This implies that a higher level of economic size is also more used in conventional and renewable energy in an economy. This outcome implies a monotonically increasing association between GDP and CE and RE.

How asymmetric estimates are deviates from the symmetric; therefore we applied the NARDL model. In NARDL estimates, coefficients of the positive shock of GDP have a positive effect on CE in the short and long run while long-run magnitude is higher than the short run. Model 4 of Table 3 shows that positive shock of GDP has a positive and significant impact on RE, whereas all negative shock of GDP is statistically insignificant. This also implies that positive shock has a significant impact on CE and RE in the short and long run, while negative shock has only insignificant effects. However, the coefficient of the error correction term has a negative and statistically significant impact on GDP per capita. This has confirmed the existence of a long-run connection between GDP per capita, CE, and RE. This finding also shows that the deviation of variables is significant from the short-run to the long-run equilibrium which is balanced by 49.7% and 48.5% per year in the last two linear and nonlinear models.

In diagnostic estimates in Panel C in Table 3, long-run cointegration is determined through F-statistics. The results show that F-test is significant in most models; therefore, cointegration has existed in our analysis. Wald statistics are insignificant, which infers that short- and long-run

asymmetries have not existed in our models. Similarly, LM and Ramsey RESET test statistics are insignificant, which is evidenced by our model being free from autocorrelation and the model being correctly specified. Furthermore, the stability of coefficients is measured through the CUSUM and CUSUM square, and the values remain within the limits and it is concluded that coefficient estimates are stable in our analysis.

The next step is to estimate the symmetric and asymmetric Granger causality test in Table 4. The results of symmetric causality indicate unidirectional causality runs from GDP to CE and RE to GDP. Nevertheless, there is no bidirectional causality existing among CR, RE, and GDP. Similarly, in asymmetric causality, negative shock in CE and RE causes the GDP in the long run, whereas there is no reverse causality possible in symmetric and asymmetric Granger causality estimates in Pakistan. The causality results for Pakistan suggest that the positive component of GDP causes CE, but negative component of GDP does not cause CE. The positive component of GDP causes RE, but the negative component of GDP does not cause RE.

# Conclusion and implications

The energy consumption role in economic development has been widely accepted and various studies have shown a positive contribution of energy consumption in accelerating the pace of economic growth. Nonetheless, the part energy plays in contaminating the environment can't be ignored, as well, and a positive association between energy consumption and $CO_2$ emissions is evidenced by many researchers. Therefore, the focus, in recent years, has been shifted from conventional or nonrenewable energy sources to renewable or green energy sources which are more conducive and friendly to the environment. Hence, keeping in view the idea of sustainable

**Table 2:**　Conventional and renewable energy impact on economic growth in Pakistan

| | ARDL | | NARDL | | ARDL | | NARDL | |
|---|---|---|---|---|---|---|---|---|
| Variable | Coefficient | t-Stat | Coefficient | t-Stat | Coefficient | t-Stat | Coefficient | t-Stat |
| *Short-run estimates* | | | | | | | | |
| D(LNCE) | 0.155** | 2.489 | | | | | | |
| D(LNCE_POS) | | | 0.217** | 2.671 | | | | |
| D(LNCE_POS(−1)) | | | 0.119* | 1.722 | | | | |
| D(LNCE_NEG) | | | −0.012 | −0.048 | | | | |
| D(LNRE) | | | | | 0.036 | 1.567 | | |
| D(LNRE(−1)) | | | | | −0.067** | −2.057 | | |
| D(LNRE_POS) | | | | | | | 0.025 | 0.640 |
| D(LNRE_POS(−1)) | | | | | | | −0.080** | −1.819 |
| D(LNRE_NEG) | | | | | | | 0.062 | 0.992 |
| D(LNLF) | 0.100 | 0.275 | −0.152 | −0.569 | 0.301 | 1.076 | 0.548** | 2.820 |
| D(LNGFC) | 0.076 | 1.482 | 0.061 | 1.106 | 0.094** | 2.363 | 0.106** | 2.505 |
| *Long-run estimates* | | | | | | | | |
| LNCE | 0.112 | 0.874 | | | | | | |
| LNCE_POS | | | 0.138 | 0.505 | | | | |
| LNCE_NEG | | | −4.101 | −0.710 | | | | |
| LNRE | | | | | 0.354** | 5.895 | | |
| LNRE_POS | | | | | | | 0.355** | 5.218 |
| LNRE_NEG | | | | | | | −0.334** | 3.239 |
| LNLF | 2.755* | 1.922 | −0.372 | −0.400 | 1.423** | 5.807 | 1.131** | 2.704 |
| LNGFC | 0.351** | 2.073 | −1.420 | −0.389 | 0.074 | 0.875 | 0.058 | 0.621 |
| C | −12.51 | −1.548 | 20.82 | 0.597 | −0.133 | −0.056 | 0.556 | 0.192 |
| *Diagnostic tests* | | | | | | | | |
| $ECM_{t-1}$ | −0.215 | −1.630 | −0.107 | −0.787 | −0.497** | −4.259 | −0.485** | −3.693 |
| Adj R2 | 0.993 | | 0.994 | | 0.996 | | 0.995 | |
| F-test | 2.483 | | 4.409 | | 8.663 | | 7.284 | |
| LM | 0.049 | | 0.641 | | 1.331 | | 1.413 | |
| RESET | 1.875 | | 1.382 | | 0.450 | | 0.067 | |
| CUSUM | S | | S | | S | | S | |
| $CUSUM^2$ | S | | S | | S | | S | |
| Wald-SR | | | 0.557 | | | | 0.120 | |
| Wald-LR | | | 1.214 | | | | 4.133** | |

Note: * and ** denote 10% and 5% level of significance, respectively. The critical values of RESET, LM, and Wald tests at the 10% level of significance is 2.70 and at 5% level 3.84

development, the countries are now trying to enhance the renewable energy share in their total energy consumption. This opens a new door for researchers, interested in energy-led growth hypothesis, to see the effect of several types of renewable energy obtained from nuclear, wind, solar, biomass, etc. sources on the economic growth of various nations.

To understand the nexus among economic growth and energy sources, in this study, we have selected Pakistan and collected data for the time span 1980–2016. The neoclassical production function of Pakistan is augmented with conventional and renewable energy, capital, and labor. We have constructed two growth models, one with conventional energy and the other with renewable energy variable as an independent variable, to see the effect of conventional and renewable energy sources on the economic growth of Pakistan. Besides, the study also analyzed the impact of the economic growth of Pakistan on conventional energy consumption as well as renewable energy consumption. Moreover, this paper applied linear and nonlinear ARDL methodology to see whether the effect of conventional and renewable energy consumption on GDP per capita of Pakistan is symmetric or asymmetric and vice versa. Furthermore, the asymmetric causal effects

**Table 3** Economic growth impact on conventional energy and renewable energy in Pakistan

| | ARDL-CE | | NARDL-CE | | RE-ARDL | | RE-NARDL | |
|---|---|---|---|---|---|---|---|---|
| Variable | Coefficient | t-Stat | Coefficient | t-Stat | Coefficient | t-Stat | Coefficient | t-Stat |
| *Short-run estimates* | | | | | | | | |
| D(LNGDP) | 0.001** | 3.465 | | | 1.002** | 2.453 | | |
| D(LNGDP_POS) | | | 0.727** | 4.019 | | | 1.297** | 2.344 |
| D(LNGDP_NEG) | | | −0.403 | −0.436 | | | 0.747 | 0.403 |
| *Long-run estimates* | | | | | | | | |
| LNGDP | 0.003** | 13.09 | | | 2.055** | 11.714 | | |
| LNGDP_POS | | | 2.074** | 8.854 | | | 2.010** | 6.419 |
| LNGDP_NEG | | | −1.150 | −0.466 | | | 1.158 | 0.423 |
| C | −1.837** | −8.956 | −0.474** | −7.733 | −15.222** | −12.754 | −2.270** | −23.76 |
| *Diagnostic tests* | | | | | | | | |
| ECM$_{t-1}$ | −0.214** | −3.925 | −0.350** | −3.792 | −0.488** | −2.788 | −0.645** | −2.999 |
| Adj R2 | 0.9930 | | 0.993 | | 0.961 | | 0.954 | |
| F-test | 5.827 | | 5.197 | | 3.563 | | 2.884 | |
| LM | 0.0080 | | 0.069 | | 0.836 | | 0.186 | |
| RESET | 1.659 | | 1.533 | | 1.300 | | 1.936 | |
| CUSUM | S | | S | | S | | S | |
| CUSUM$^2$ | S | | S | | S | | S | |
| Wald-SR | | | 0.740 | | | | 1.120 | |
| Wald-LR | | | 2.869* | | | | 2.752* | |

Note: * and ** denote 10% and 5% level of significance, respectively. The critical values of RESET, LM, and Wald tests at the 10% level of significance are 2.70 and at 5% level 3.84

**Table 4** Symmetric and asymmetric Granger causality

| | Symmetric causality | | | Asymmetric causality | | |
|---|---|---|---|---|---|---|
| | | F-Statistic | Prob. | | F-Statistic | Prob. |
| | LNCE →LNGDP | 0.071 | 0.931 | LNCE_POS →LNGDP | 0.356 | 0.702 |
| | LNGDP →LNCE | 5.235** | 0.011 | LNGDP →LNCE_POS | 5.367** | 0.010 |
| | LNRE →LNGDP | 3.682** | 0.037 | LNCE_NEG →LNGDP | 6.029** | 0.006 |
| | LNGDP →LNRE | 2.015 | 0.150 | LNGDP →LNCE_NEG | 0.312 | 0.734 |
| | | | | LNCE_NEG →LNCE_POS | 0.997 | 0.381 |
| | | | | LNCE_POS →LNCE_NEG | 1.826 | 0.179 |
| | | | | LNRE_POS →LNGDP | 6.093** | 0.006 |
| | | | | LNGDP →LNRE_POS | 0.766 | 0.473 |
| | | | | LNRE_NEG →LNGDP | 2.755* | 0.080 |
| | | | | LNGDP →LNRE_NEG | 1.497 | 0.240 |
| | | | | LNRE_NEG →LNRE_POS | 4.135** | 0.026 |
| | | | | LNRE_POS →LNRE_NEG | 2.786* | 0.078 |
| | | | | LNGDP_POS →LNCE | 4.321** | 0.024 |
| | | | | LNGDP_NEG →LNCE | 0.454 | 0.612 |
| | | | | LNGDP_POS → LN RE | 2.864* | 0.075 |
| | | | | LNGDP_NEG → LN RE | 1.542 | 0.231 |

between the energy variables and economic growth are also discussed.

The findings of symmetric GDP models established that conventional energy did improve the economic prosperity of people of Pakistan in the short run, though in the long run conventional energy did not show any significant effect on the economic growth of Pakistan. Conversely, the renewable energy hurt the economic growth of Pakistan in the short run, while in the long run the renewable energy improved Pakistan's GDP per capita. As for the asymmetric GDP, models are concerned, positive shocks in conventional energy proved to be a catalyst in achieving higher GDP capita of Pakistan in short-run, whereas the negative shocks did not have any noticeable effects. On the other hand, the short-run positive change in renewable energy exerted a negative effect on the economic growth of Pakistan and the negative change had produced insignificant effects. In the long run, the increased use of renewable energy helped in attaining the economic growth of Pakistan while the decreased renewable energy use stalled the economic growth of Pakistan. These findings confirmed the asymmetric impact of increased and decreased use of renewable energy on the GDP growth of Pakistan. However, the asymmetric estimates of conventional energy did not show any visible effect on the economic growth of Pakistan.

Next, the symmetric estimates of GDP exerted positive impacts on the consumption of both conventional and renewable energy both in the short and in long run, while in asymmetric energy models, the positive change in GDP, in the short run, has positively influenced the energy consumption of both sources. Nevertheless, the reduced GDP has insignificantly impacted the energy sources in the short run. Likewise, in the long run, the consumption of both energy sources are positively influenced by increased GDP per capita, though the decline in the economic growth of Pakistan did not show any significant impact on both sources of energy consumption.

Finally, the symmetric and asymmetric causality provided important results. First, we found that symmetric unidirectional causality running from GDP→CE and RE→GDP implies conservation and growth hypothesis, respectively. Similarly, the evidence of conservation hypothesis has been found when the one-way causality is running from GDP →CE_POS, and we observed growth hypothesis in the case of one-directional causality from RE _POS→ GDP. On the same lines, we have found evidence of the conversation hypothesis when GDP_POS was causing CE and RE.

The findings of the study have put forth some significant policy implications. The renewable energy has proved to be an important determinant of GDP growth of Pakistan. From the asymmetric results, we came to know that positive change in renewable energy actually boosted GDP growth of Pakistan; hence, Pakistan should invest more in renewable energy

resources to attain sustainable development goals. Moreover, renewable energy sources will provide additional benefits of reducing carbon footprints. Causality results supported growth hypothesis in the case of renewable energy and GDP which infers that renewable energy is a significant factor in boosting the economic growth of Pakistan and a decline in the use of renewable energy could actually stem from the economic growth of Pakistan. On the other side, the conservation hypothesis in the case of causality running from GDP→ CE_POS suggested to policymakers that energy conservation policy will have little or no impact on GDP growth of Pakistan. Nevertheless, asymmetric causality made it clear that positive shock in GDP Granger caused conventional energy, whereas reduced GDP did not cause NEG. This result implied that the conservation hypothesis was only valid when there was a positive shock in GDP.

Like every study, this study is not free from limitations and the major one is that this is only relevant to Pakistan. In the future, attention can be paid to a much larger group of countries and the energy-growth nexus can be tested by using nonlinear techniques. Furthermore, the contribution of solar, wind, and nuclear energy in the economic growth should be separately verified which will provide us clear insights as to which one is more efficient.

## Declarations

**Ethical approval**   Not applicable.

**Consent to participate**   I am free to contact any of the people involved in the research to seek further clarification and information

**Consent to publish**   Not applicable.

**Competing interests**   The authors declare no conflict of interest.

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