Environment, Development and Sustainability (2023) 25:2419–2442
https://doi.org/10.1007/s10668-022-02133-9

Structural transformations and conventional energy-based power utilization on carbon emissions: empirical evidence from Pakistan

Hamisu Sadi Ali[1] · Malayaranjan Sahoo[2] · Md. Mahmudul Alam[3] · Idris Isma'il Tijjani[4] · Abul Quasem Al-Amin[5,6,8] · Adeel Ahmed[7]

Received: 13 February 2020 / Accepted: 9 January 2022 / Published online: 28 January 2022

Abstract

Economic structural changes are a major factor that has a big impact on most of a country or region's economic systems and operations, as well as the environment. This study looks at how conventional energy-based power use affects carbon emissions in Pakistan through a structural change analysis of the country from 1971 to 2018. It uses the autoregressive distributed lags (ARDL) method and covers the period from 1971 to 2018. The long-term findings from the ARDL suggest that economic expansion, growth and development, and agro production lead to declining carbon emissions and in turn, will improve the state of the environment. Precisely, an increase in 1% of economic expansion and agricultural production will reduce carbon emissions by 1.26% and 0.53%, respectively. However, the current use of conventional energy to make electricity is causing carbon dioxide to be released into the air. People who live in cities use more conventional energy, which means that the amount of carbon dioxide they produce will go up by 1.53% for every 1% change in conventional energy use. This means that there are strong links between urbanzation and carbon emissions. Government and industry policymakers should encourage people to use renewable and conventional energy sources, encourage them to invest more in green-related businesses, and provide more social amenities and better infrastructure in Pakistan's rural areas, to name a few things. Doing so will help to reduce the continuing and uncontrolled influx of people to the country's cities, which simply further endangers the natural environment.

Keywords Carbon emission (CO_2) · Structural transformation · Energy use · Financial development · Urbanization · Pakistan · ARDL

✉ Md. Mahmudul Alam
rony000@gmail.com

Extended author information available on the last page of the article

1 Introduction

The nexus among the 3Es, i.e. Energy, Economy, and Environment, is receiving much scholarly attention and is the subject of keen interest shown by international environmental agencies and policymakers globally (Winfield & Dolter, 2014). The main goal of every country is to grow their economy. To do this, countries used to rely on a lot of traditional energy, which led to environmental damage or pollution (Rauf et al., 2018). Early on, most economies rely on fossil fuel or conventional energy sources, like coal and oil, for their electricity (Nehrenheim, 2013). People and businesses can get an idea of how well a country is using and developing its conventional energy-based power resources over time, which gives them a sense of how things are going (Akpan & Akpan, 2012). Economic growth and climate change are two other important issues that a country needs to think about when it comes to its economic policies (e.g. Mohsin et al., 2021; Sharma et al., 2021).

The International Energy Agency (2019) stated CO_2 emissions from the world's energy sources rose by 1.7% in 2018. There were a lot of these emissions coming from countries that were just starting to become more wealthy (de Vries & Ferrarini, 2017). Figures from the World Bank (2018) show that between 1970 and 2016, the level of emissions rose by 1440%. Consequently, energy-based power use is expected to increase significantly from now through 2040. There are ways to keep global warming below 2 °C, like cutting back on greenhouse gas emissions from all industries, like land use and food production. Those countries can keep global warming in the 1.5–2 °C range if they cut CO_2 in all parts of their economies.

In addition, most Asian countries are still in the early stages of development, which means that all governments are trying to make the best use of their conventional energy-based power sources in order to grow their economies and businesses (Weimin et al., 2021). In Pakistan, oil and gas are the main sources of conventional energy-based power (54% of conventional energy-based power). This means that a lot of CO_2 is released. In fact, a major source of pollution in Pakistan comes from the unregulated production and use of conventional energy-based power (Hussain et al., 2012). There were more CO_2 emissions in Pakistan in 2015–2016 than there were in 2014–2015, according to data from the World Bank (2019). This is even though the emissions were 34.04 Gt in 2014–2015. However, since 2000, the total emissions have gone up by about 40%. Carbon dioxide emissions have risen because of structural changes in every sector, more economic growth, industrialization, and a lot of urbanzation (Nejat et al., 2015). In addition, there were only a few studies that looked at how industrialization in Pakistan affected carbon (CO_2) emissions. To find out the answer to this question, this study looks into how macroeconomic factors affect environmental quality. In Pakistan, there aren't any studies yet that show what will happen to the country's economy when it comes to carbon emissions.

At the national level, Pakistan has looked at things like conventional energy-based power growth and use, as well as changes in the environment (Ali et al., 2020a, 2020b). Some other forecasts have also been used to make it easier for people to make decisions. These include urbanzation and industrial development (Saleem et al., 2020). It's still not clear how much total conventional energy use, environmental problems, and structural change in the Pakistani economy can be measured. However, there is a big difference in the research that is available. All in all, previous research hasn't categorized important variables in terms of conventional energy-based power use, structural change, and environmental degradation. People in Pakistan are going to have to make structural changes to the country's economy, like changing how farming, service, and industry work. However, the role structural change in CO_2 emissions plays in the economy, economic growth, conventional energy-based power use, industrialization, and urbanzation is still unknown.

These three structural sectors (agriculture, service sector, and industry) make up the foundation of any society, but now they need to be improved to cut CO_2 emissions, so they need to be changed. Slow structural changes in Pakistan's economy, on the other hand, could be another way to help keep the climate stable. In the past, people didn't pay attention to the connection between economic growth and development, conventional energy-based power use, urbanzation, and industrialization, as well as their impact on the environment (e.g. CO_2 emissions) caused by the focus on economic progress. Structural transformation is a term that encompasses everything that needs to be done for Pakistan to have a well-balanced economy. Aside from that, using the ARDL method to look at and check Pakistan's carbon emissions from 1971 to 2018 is new and has important policy implications.

The aim of this study is to find out how Pakistan's structural changes and traditional energy use affect CO_2 emissions in the country. Pakistan is a good place to look at this because the use of conventional energy-based power rose 61.4% between 1971 and 2016. At the same time, Pakistan is getting a lot of conventional energy from other countries to meet its growing needs (Nayyar et al., 2014). Pakistan doesn't have enough conventional energy-based power to meet its needs. Though Pakistan is a developing country, the demand for conventional energy-based power has skyrocketed because of industrial development and population growth. Conventional energy-based power production hasn't kept up with the demand, though (Zhang et al., 2018). It was found that the country's level of carbon dioxide, methane, and nitrous oxides rose, respectively, by 33.2%, 44.5%, and 97.4%. Carbon emissions from industrial and production sectors made up 23.84% of the country's overall combustion in 2016. Developing countries around the world are very concerned about climate change because they rely on heavy industry and already warm weather. Rising Asian countries, on the other hand, have very different climatic changes than they did a few decades ago. If individuals live in Pakistan, this is a big deal because it's still growing and becoming more industrial and urban. To keep the pace of economic development and growth high takes a lot of resources. The government of Pakistan would never risk economic growth and development to try to solve the climate change problem. In addition, this paper focuses on a single period, from 1971 to 2018. The autoregressive distributed lags (ARDL) bound test is also used in this study. Johansen and Julius cointegration as well as Granger causality tests were used to confirm the results of this study. This means that the way the study is done is very careful. This study, on the other hand, aims to help government and industry policymakers control emissions at the sectoral level and then set a goal that can be reached at the aggregate level.

There are four sections in the rest of the study: Sect. 2 talks about the literature review; Sect. 3 talks about the data sources and methodology; Sect. 4 talks about the results, and the last section talks about the conclusion and policy implications.

2 Literature review

2.1 Economic growth and CO_2 emissions

In terms of the energy consumption-growth nexus, the empirical literature gives ambiguous and contradictory findings. The researcher used different econometric techniques, different time periods, and chose a different country to study. This led to mixed results.

Nearly 30 years ago, many studies looked into the link between economic growth and the use of conventional energy-based power, as well as carbon emissions around the world. A lot of people saw that SO_2 was linked to NO_2 in the early 1990s, like Grossman and Krueger (1993) and Panayotou (1993). They found that there were no significant connections between deforestation, trade intensity, per capita GDP, and population. Study: Wu et al. (2018) looked at how economic growth and CO_2 emissions are linked in both developed and developing countries. They looked at both. They use the decoupling method to find out how they feel about each other. Found that decoupling is more stable in developed countries like the UK and Germany. Decoupling in the United States is less stable. However, in developing countries, decoupling changes a lot and isn't always stable. Selden and Song (1994) looked at Turkey and looked at different GHGs like SO_2, NO_2, and CO_2. They also looked at how these GHGs and GDP per person were linked. The authors found that there was a strong connection between the variables. Heil and Selden (1999) looked into the relationship between foreign exchange and carbon emissions by using econometric methods to look at carbon emissions from 1950 to 1992. They looked at 132 countries in their study. There is more industrial activity in lower-income countries, which causes more carbon emissions and fewer carbon emissions from more wealthy countries. A study by Cole (2004) looked at developed countries and said that trade openness and pollution have a strong connection. Also, using ARDL, Johansen Cointegration, and Granger relationship tests, a study by Ghosh (2010) in India found that income and carbon dioxide (CO_2) emissions go both ways. Many studies have found that economic growth and CO_2 emissions don't always go hand in hand (Aktar et al., 2021; Alam & Murad, 2020; Murad et al., 2019; Paramati et al., 2017; Umar et al., 2021).

A study by Hussain et al. (2012) looked at time-series data from 1971 to 2006 that was based on the environmental Kuznets curve (EKC). They used the Johansen Co-integration VECM and Granger relationship tests to look at issues. They found that economic growth and CO_2 emissions go hand in hand. Khan et al. (2020a, 2020b) used the ARDL method to study CO_2. They found that when the economy grows, CO_2 levels go down. Khan et al., (2019a, 2019b), on the other hand, used the same method and found that economic growth in Pakistan during 1971–2016 led to less CO_2. Because the effects of economic growth and CO_2 in different countries can also be different, this is also true. This could be because of the addition of other variables and the use of different sample times. The link between economic growth and CO_2 has been looked at by many people, and they found conflicting success (Bakhsh et al., 2017; Khan et al., 2019a, 2019b; Lahiani, 2018; Mirza & Kanwal, 2017; Siddique, 2017).

A lot of studies have looked into how carbon emissions and different macroeconomic variables don't always work well together. For example, Wang et al. (2016a, 2016b) found that urbanzation, carbon emissions, and conventional energy-based power use are all linked and have a positive effect on each other. Economic growth and growth, development and expansion, use of conventional energy-based power, and CO_2 emissions were all linked in OECD countries for a long time (Mercan & Karakaya, 2015). Once CO_2 emissions and other things change, the relationship between the two changes as well (Ahmad & Du, 2017; Danish et al., 2017). Environmental problems can arise as a result of the first regime's growth, development, and expansion (Heidari et al., 2015). In Pakistan, for example, there is a two-way relationship between economic growth, development, and CO_2 emissions, as well as conventional energy-based power use (Mirza & Kanwal, 2017). In the long run, carbon (CO_2) emissions and conventional energy-based power use both have a direct effect on each other (Danish et al., 2017). Indeed, the results from these studies have been mixed or ambiguous. Therefore, the links between these variables are being questioned and open to controversy.

2.2 Energy consumption and CO_2 emissions

The relationship between energy use and CO_2 emissions has been studied a lot. Chen et al. (2016) looked at 188 countries to see how energy use and CO_2 emissions affected them. They found that there is only one way that energy use and CO_2 go together. They conclude that energy efficiency can be one of the best ways to cut down on emissions in both developed and developing countries. Ramanathan (2002) did a cross-country study of energy use and CO_2. There are a lot more emissions coming from the country that relies mostly on heavy industries than there are from small and medium-sized industries. In 2016, a study by Wang et al. looked at CO_2 emissions in China. They found that the shock from energy consumption to CO_2 emissions isn't very strong. They also looked at Granger causality and found that there was only one way that energy use and CO_2 were linked. Research that was done in both developed and developing countries are many (Jan et al., 2021; Khan et al., 2021; Petrovic & Lobanov, 2021; Rahman et al., 2021; Raza & Shah, 2020; Villanthenkodath et al., 2021; Yasin et al., 2021).

Zhang et al., (2018) examined a time series data from 1971 to 2006 in Pakistan confirming a long-term two-way relationship between carbon emissions/per capita and conventional energy-based power utilization/ per capita. Another study by Aye and Prosper (2017) explored the effects of economic growth, growth, and conventional energy-based power utilization and documented mixed findings such as less economic growth leads to lower carbon (CO_2) emissions and vice versa. Additionally, dynamic causality was discovered between economic growth, electricity use, and carbon (CO_2) emissions (Mirza & Kanwal, 2017). Their analysis revealed that in both the short- and long-term, strong causal outcomes of Granger testing are suggested to exist between carbon (CO_2) emissions, conventional energy-based power use and economic development, growth, and progress in the presence of bidirectional causality. They did suggest that in the overall conventional energy-based power mix, the government should concentrate on building resources to guarantee enough conventional energy-based power for the economy by increasing renewable gradually conventional energy-based power resources. Javid and Sharif (2016) indicate that a unidirectional source of growth and conventional energy-based power has been found, yet contrary to this, Aqeel and Butt (2001) detected no cointegration between these variables for Pakistan. In another recent analysis, Zaidi et al. (2018) found that Pakistan's carbon (CO_2) emissions are based on non-renewable conventional energy-based power rather than renewable conventional energy-based power. Very recently, Khan et al. (2019a, 2019b) using the ARDL approach for a study on Pakistan covering the period 1971–2016, measured the globalization effects, environmental conditions and electricity use on the carbon (CO_2) emissions. They find that the impact on carbon (CO_2) emissions is significant, such as conventional energy-based power use, foreign direct investments, financial growth, trade, and international political, and social globalization. Conversely, economic expansion and growth, urbanization, and innovation have reduced carbon emissions.

2.3 Financial development and CO_2 emissions

There has been debate about the inter-link between financial development and CO_2 emissions. Many researchers also highlighted that due to advancement of technology and energy efficiency in the financial sector, leads to reduce carbon emission (Nasrollahi et al., 2020; Taghvaee et al., 2017). The researcher argued that financial openness and financial development attract more foreign investment in the domestic financial sectors, which leads to the improvement of R&D in this sector and reduces carbon emissions (Alam et al., 2016; Murad et al., 2018). A study by Zaidi et al. (2019) investigated the effects of globalization and financial development in the case of Asia–Pacific countries during 1990–2016. They have used the continuously updated fully modified (CUFM) model to analyse the results. They found financial development bring down CO_2 emissions in the sample period. Bayar and Maxim (2020) examined the relationship between the roles of financial development, energy consumption on CO_2 emissions in 11 European countries. They found that some of the EU countries have shown, financial development and energy consumption have a positive effect on carbon emissions. They suggested that firms choose to grow their output through financing rather than adopt energy-saving solutions. Similarly, Abbasi and Riaz (2016) examined the effect of financial development and economic growth on carbon emissions in emerging country cases. They apply the ARDL approach to find out the results. They found financial liberalization plays an important role in mitigating emissions. They also highlighted that the magnitude of financial development is less than the economic growth on carbon emissions. A recent study by Bui (2020) examined the transmission channel of financial development on environmental quality. They found that income had a positive effect on the quality of the environment. The growth of the financial sector means that more energy is used and, as a result, more pollution is released. The financial development and macroeconomic variables of CO_2 emissions are looked at in a lot of studies (Ali et al., 2020, 2020b; Anwar et al., 2021).

A study by Muhammad and Ghulam Fatima (2013) examined the impact of financial development, economic growth, and energy consumption on CO_2 emissions in Pakistan during 1971–2011. They employ the ARDL bounds testing approach to analyse the results. They found financial development has shown considerable positive signs on environmental quality. It indicates that financial sectors growing at the expense of environmental quality. Similarly, a recent study on Pakistan Khan et al. (2020a, 2020b) investigated the impact of financial development and other macroeconomic variables. They have applied novel methodology like the dynamic ARDL approach to get the results. It reveals that financial development and economic growth show a positive impact on CO_2 emissions.

2.4 Structure of the economy and CO_2 emissions

Sohag et al. (2017) surveyed the effects of shifts in industries on environmental sustainability in middle-income countries. According to them, the use of conventional energy-based power and expansion of the manufacturing and utility industries strongly describe carbon emissions in these economies. Meanwhile, the increase in population has no significant impact on carbon emissions. Ge et al. (2016) identify the giving and taking roles played by various industry sectors on greenhouse gas (GHG) emissions for China. The outcomes specify that services were the largest emitters of total (indirect and direct) emissions in that country. For instance, industries including agriculture, conventional energy-based power utilization, service, and trade openness damage the environment in both short and long-term periods though the growth of urbanization leads to a better environment (Rauf et al., 2018). Bidirectional causality between conventional energy-based power utilization and carbon emissions was found from the perspective of EKC (Ali et al., 2017a, 2017b). Gokmenoglu and Sadeghieh (2019) used data from 1960 to 2011 to test the association between financial development and environmental impacts in Turkey and showed that financial growth has major effects on GHG emissions. As determinants of environmental degradation, they employed a multivariate paradigm that focuses on economic expansion and growth and development, growth, expansion, and conventional energy-based power utilization. An earlier study that applied the Granger causality test by Gokmenoglu et al. (2015) confirmed a one-way correlation between financial growth and GHG emissions.

Likewise, Shahbaz et al. (2013a, 2013b) found financial growth exerts negative effects on GHG emissions. In contrast, other studies showed that economic expansion and growth and development, growth, expansion, and conventional energy-based power utilization increased carbon emissions. For example, in West African countries, Zhang (2011) states that only domestic credits provided by the financial sector resulted in a significant rise in carbon emissions. Similarly, with an application of a panel error-correction model, Xing et al. (2017) tested the effects of fiscal expansion on GHG emissions. Their empirical outcomes confirmed that financial growth leads to more carbon emissions, and such an effect not only highlights the importance of regional difference but also reflects various stages of economic expansion, growth and development. As per the best of the author's knowledge, there are very few studies found in the case of Pakistan investigating the sectoral effects on environmental quality. Hence, this paper would be contributed to the existing studies on the environmental issue.

2.5 Urbanization and CO_2 emissions

The relationship between urbanization and environmental pollutions has been discussed by many researchers. Though urbanization is not directly linked with the environment, it has many indirect channels to associate with environmental issues (Abbas et al., 2021). Sadorsky (2014) used advanced econometrics techniques to gauge the relationship between urbanization and CO_2 emissions in emerging countries. They found ignoring the urbanization variables from the model leads to a reduction of environmental emissions. They also show that urbanization has a positive relationship with CO_2 emissions. Zhu et al. (2012) examine the nexus between urbanization and CO_2 emissions in 20 emerging countries. They found that there is no evidence of the EKC hypothesis existence in the model. Shahbaz et al. (2016) use the STIRPAT model to examine the long-run and short-run relationship between urbanization and CO_2 emissions. They found that at the initial stage of economic development urbanization reduces emission, whereas, at the subsequent development of urban areas and installation of industries, the pollution level increases at an increasing rate. They indicate U shape relationship exists between urbanization and CO_2 emissions in Malaysia in the sample period. A study by Salahuddin et al. (2019) examines the inter-link between globalization, urbanization, and CO_2 emissions in South Africa using structural break analysis in the ARDL model. They found that urbanization increases CO_2 emissions in these countries. Suggest that it must pursue other options for reducing emissions, the most promising of which is unquestionably redoubling its efforts to promote the use of renewables in its energy production, gradually shifting from a mostly coal-fired generation of energy to solar and wind power energy supply methods.

This is how Ali et al. (2019) look at the link between urbanzation and CO_2 emissions in Pakistan from 1972 to 2014. They use the ARDL method. The results show that all of the variables are linked together, and the long and short-term results show that urbanzation led to more carbon emissions in these counties during the study period. A new study by Abbasi et al. (2021) used a new dynamic ARDL method to look at the relationship between urbanzation and CO_2 emissions in Pakistan. They found that urbanzation has a positive effect on both economic growth and the environment. In the same way, Anser (2019) looks at how urbanzation and the environment in Pakistan are affected by factors like human capital and energy use. They found that urbanzation isn't being as good for the environment as it should be.

There were a lot of mixed results from the empirical types of literature when it came to economic growth, energy use, financial development, the structure of the economy, urbanzation, and CO_2 emissions. Many studies have been done on this at the aggregate level, but very little has been done at the sectoral level, especially in Pakistan. One important study to fill in the gaps about environmental issues at the sectoral level is this one.

3 Methodology

3.1 Econometric models

The main objective as shown in Eq. (1) is to empirically examine the impact of the independent variables (EG, EC, FD, IND, SER, AGR, URB) on carbon dioxide emissions in Pakistan. The simple form of the proposed model is as follows:

$$CO_2 = f(\mathrm{EG}, \mathrm{EC}, \mathrm{FD}, \mathrm{IND}, \mathrm{SER}, \mathrm{AGR}, \mathrm{URB}) \tag{1}$$

Furthermore, to form specified the ARDL modelling form of the vector error correction model (VECM), this study followed the work of earlier scholars (Ali et al. 2016, 2017a, 2017b; Fosu & Magnus, 2006) and the model is re-written in full form:

$$\begin{aligned}\Delta \ln \mathrm{CO}_{2t} = {} & \alpha_0 + \alpha_1 \ln \mathrm{CO}_{2t-1} + \alpha_2 \ln \mathrm{EG}_{t-1} + \alpha_3 \ln \mathrm{EC}_{t-1} + \alpha_4 \ln \mathrm{FD}_{t-1} + \alpha_5 \ln \mathrm{IND}_{t-1} \\ & + \alpha_6 \ln \mathrm{SER}_{t-1} + \alpha_7 \ln \mathrm{AGR}_{t-1} + \alpha_8 \ln \mathrm{URB}_{t-1} + \sum_{i}^{p} \gamma_i \Delta \ln \mathrm{CO}_{2t-1} \\ & + \sum_{j}^{q} \delta_j \Delta \ln \mathrm{EG}_{t-j} + \sum_{l}^{p} \varphi_l \Delta \ln \mathrm{EC}_{t-l} + \sum_{l}^{p} \omega_k \Delta \ln \mathrm{FD}_{t-m} + \sum_{m}^{q} \eta_m \Delta \ln \mathrm{IND}_{t-n} \\ & + \sum_{m}^{q} \eta_m \Delta \ln \mathrm{SER}_{t-o} + \sum_{m}^{q} \eta_m \Delta \ln \mathrm{AGR}_{t-p} + \sum_{m}^{q} \eta_m \Delta \ln \mathrm{URB}_{t-p} + \varepsilon_t \end{aligned} \tag{2}$$

where $\ln CO_2$ = the natural logarithm of carbon (CO_2) emissions, $\ln \mathrm{EG}$ = the natural logarithm of economic expansion and growth, $\ln \mathrm{EC}$ = the natural logarithm of conventional energy utilization, $\ln \mathrm{SER}$ = the natural logarithm of services, $\ln \mathrm{AGR}$ = the natural logarithm of agriculture, $\ln \mathrm{FD}$ = the natural logarithm of financial development, $\ln \mathrm{IND}$ = the natural logarithm of industry, $\ln \mathrm{URB}$ = the natural logarithm of urbanization, and subscript t = time period. The notations/symbols p, q, l, m, i, j, n, t, and k serve as a descriptor of each individual variable in the model. There are two stages followed and the first stage seeks to estimate Eq. (2) based on OLS calculated in the first stage, and in the second stage, the Wald test and F-test evaluated. The second test evaluates the lagged variables by using the joint significance of the coefficients. Doing so will make it possible to observe if there is a long-run correlation among the variables.

After establishing the long-term relationship, the subsequent task is to test the null hypothesis $H_0 = \beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = \beta_6 = \beta_7 = \beta_8 = 0$, which states there is no long-run relationship contrary to the alternative hypothesis $H_a \neq \beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq \beta_5 \neq \beta_6 \neq \beta_7 \neq \beta_8 \neq 0$. The latter signifies the presence of such a relationship among constructs.

If the estimated F-test value is bigger than the critical value (upper bound) this indicates that the null hypothesis on cointegration (Pesaran et al., 2001) is rejected. Specifically, it confirms the long-run association between the variables is present. Nevertheless, the null hypothesis cannot be denied if the calculated F-test is lower than the critical value (upper bound). Precisely, it indicates no long-run relationships among variables exist. Additionally, outcomes will be undecided if the calculated F-test values fall between the lower and upper critical values (Pesaran & Pesaran, 1997). Equation (3) follows the identified ARDL long-run coefficients and is written as:

$$\ln CO_{2t} = \beta_0 \sum_{i=1}^{p} \gamma_i \Delta \ln CO_{2t-1} + \sum_{j=0}^{q1} \delta_j \ln EG_{t-j} + \sum_{i=0}^{q2} \varphi_l \ln EC_{t-l} + \sum_{m=1}^{q3} \eta_m \ln FD_{t-m} + \sum_{m=0}^{q4} \cup_n \ln IND_{t-n} + \sum_{n=0}^{q5} \omega_n \ln SER_{t-o} + \sum_{o=0}^{q6} \rho_n \ln AGR_{t-p} + \sum_{m=0}^{q7} \in_n \ln URB_{t-q} + \varepsilon_t \tag{3}$$

Schwarz Bayesian Criterion (SBC) is applied to choose the lag length of the model and use the error correction model to conclude the variables' short-term correlation:

$$\ln CO_{2t} = \beta_0 \sum_{i=1}^{p} \gamma_i \ln CO_{2t-1} \sum_{j=0}^{q1} \delta_j \ln EG_{t-j} + \sum_{i=0}^{q2} \varphi_l \ln EC_{t-l} + \sum_{m=1}^{q3} \eta_m \ln FD_{t-m} + \sum_{m=0}^{q4} \cup_n \ln IND_{t-n} + \sum_{n=0}^{q5} \omega_n \ln SER_{t-o} + \sum_{o=0}^{q6} \rho_n \ln AGR_{t-p} + \sum_{m=0}^{q7} \in_n \ln URB_{t-q} + +\vartheta ecm_{t-1} + \varepsilon_t \tag{4}$$

Then to check the ARDL model fit, this study considered the regular diagnostic tests like serial correlation, Ramsey's misspecification, Lagrange multiplier, and heteroscedasticity, etc. To assess the long-run coefficients' stability and short-run dynamics, this study estimated the cumulative sum of squares of recursive residuals (CUSUMSQ) and cumulative sum of recursive residuals (CUSUM) as recommended by Pesaran (1997). Furthermore, the robustness of the main findings is checked through Johansen and Juselius (1990) cointegration test as well as Granger (1969) causality test.

3.2 Data

World Development Indicators and the World Bank are the two main sources for this study's data obtained, specifically for the years 1971–2018. Economic expansion, growth and development, and carbon emissions both are estimated by carbon emissions in kilogram (kg) per 2010 US$ of GDP with GDP price based. Conventional energy-based power use (kilogram of oil equivalent/capita) measures the level of conventional energy-based power utilization. Domestic credit given to the private sector (as % of GDP) is considered to be financial growth, while the industry is measured by the GDP ratio based on the value-added by the industry. Moreover, services are measured by the GDP ratio of the value of the service added, and agriculture is measured by the GDP ratio of agricultural value-addition. In this study, we used urban population/total population (ratio) to represent urbanization.

Figure 1 highlights the nature and movements of the variables during the study period. For example, a steady decline in CO_2 emissions from around 2008 up to 2018 may have been due to better and enforceable environmental protection policies in Pakistan. Conventional energy-based power utilization steadily increases, and the country's GDP shows much promise as it consistently improves from 1970 to 2018. Moreover, the service sector is gaining traction and despite the fluctuations, it did register a slight increase from 2010 to the present day. Urbanization has also steadily risen since the graph indicates a direct upward trend from 1970 to 2018. This means the issue of rural to urban migration is still prevalent in the country, possibly due to a shortage of basic amenities and infrastructure in rural areas.

4 Empirical results and discussion

4.1 Descriptive statistics

The descriptive statistics including Jarque–Bera, mean, maximum, and skewness, etc. are presented in Table 1. As expected, it is evident that significant structural changes occurred in all areas including conventional energy-based power utilization, urbanization, carbon

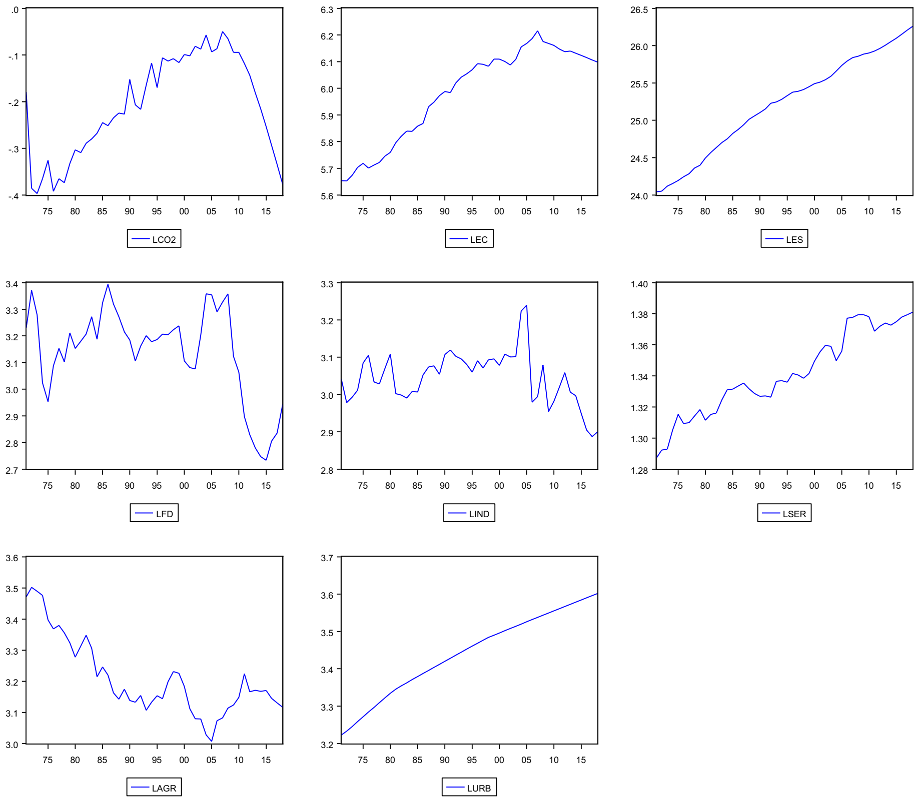

Fig. 1 Time series plots of the variables 1975: 2015

Table 1 Descriptive indicators

Variables	Observations	Mean	Std. Dev	Minimum	Maximum	Skewness	Kurtosis	Jarque–Bera	Probability
CO_2	48	0.815	0.086	0.672	0.951	−0.144	1.687	3.613	0.164
EG	48	1.08	6.45	2.76	2.54	0.551	2.222	3.641	0.161
EC	48	401.653	67.288	284.974	500.432	−0.441	1.714	4.868	0.087
FD	48	23.438	3.794	15.386	29.786	−0.536	2.591	2.636	0.267
IND	48	21.078	1.502	17.942	25.528	0.419	4.126	3.948	0.138
SER	48	46.063	4.736	37.419	53.468	0.146	1.870	2.724	0.256
AGR	48	24.981	3.256	20.219	33.175	1.071	3.294	9.352	0.009
URB	48	31.410	3.381	25.084	36.666	−0.228	1.906	2.807	0.245

(CO_2) emissions, and economic expansion and growth and development. Moreover, the degree of inequality of data information was evaluated through skewness. The skewness value of zero (0) indicates 'regular'; extended rightward tails represent the positive, and extended leftward tails refer to the negative. Besides, kurtosis calculates the uniformity to identify whether data are dispersed. Mesokurtic indicates the natural dispersion of data where the kurtosis value is 3. The leptokurtic hypothesizes peaked arc which means the kurtosis value is greater than 3. The negative value of kurtosis is less than 3 and it refers to the platykurtic of the flattened arc. The Jarque–Bera test (JB test) makes it possible to relate the normality of the series to the data investigated in this study.

4.2 Correlation test

A quantified analysis is reported in Table 2 which highlights the interrelationships among the variables. The correlation among these variables reveals that the relationship is satisfactory, considering the values obtained are vividly interrelated with CO_2 (carbon emissions) to nearly 80% during the study period. Unquestionably, conventional energy-based power utilization, agriculture, services, industry, economic expansion and growth, urbanization, and financial development produce CO_2 emissions and their respective amounts are 71.8%, 69.5%, 58.5%, 53.2%, 42.1%, 40.9%, and 19.5%.

4.3 Unit root test

The main intention of the traditional model is to observe the order of the variables' integration before assessing the main empirical model. Hence, the unit root test is performed applying two popular methods, these being the Phillips Perron (PP) and Augmented Dickey–Fuller (ADF) tests. The results from the unit root tests (Table 3) indicated that carbon emissions, growth and economic structure, financial development, conventional energy-based power utilization, services, and agriculture are non-stationary at level form. Although the variables in this study become stationary at the first differential-difference, meaning that these six variables are all *I* (1) variables following the PP and ADF unit root

Table 2 Correlation matrix of the variables

Variables	1	2	3	4	5	6	7	8
1. Carbon dioxide	1.0000							
2. Conventional energy-based power growth	0.409	1.0000						
3. Conventional energy-based power utilization	0.718	0.855	1.0000					
4. Financial development	0.195	0.517	0.205	1.0000				
5. IND	0.421	0.303	0.058	0.417	1.0000			
6. SER	0.532	0.951	0.895	0.399	0.255	1.0000		
7. AGR	0.695	0.672	0.866	0.049	0.245	0.753	1.0000	
8. URB	0.585	0.960	0.949	0.410	−0.131	0.958	0.819	1.0000

IND industrial sector value-added ratio of GDP, *SER* service sector value-added ratio of GDP, *AGR* agriculture value-added ratio of GDP, *URB* urban population percentage of total population

Table 3 Outcomes from PP and ADF and unit root tests for the years 1971 to 2018

Variables	ADF		PP		Order of integration
	Constant without trend	Constant with trend	Constant without trend	Constant with trend	
Level					
$\ln CO_{2t}$	−2.217	−2.027	−2.229	−2.029	–
$\ln EG_t$	3.149	−2.192	5.668	−2.317	–
$\ln EC_t$	5.168	0.499	4.992	0.406	–
$\ln FD_t$	−1.528	−3.182	−1.359	−1.665	–
$\ln IND_t$	−3.785***	−3.285*	−2.192	−1.430	*I*(0)
$\ln SER_t$	−0.163	−2.994	0.073	−2.994	–
$\ln AGR_t$	−0.154	−2.395	−0.060	−2.801	–
$\ln URB_t$	0.558	−3.375*	−1.472	−2.870	*I*(0)
First difference					
$\ln CO_{2t}$	−7.184***	−7.155***	−7.176***	−7.152***	*I*(1)
$\ln EG_t$	−7.091***	−8.585***	−7.083***	−14.065***	*I*(1)
$\ln EC_t$	−4.484***	−6.300***	−4.638***	−6.353***	*I*(1)
$\ln FD_t$	−3.335**	−3.426*	−5.897**	−5.950***	*I*(1)
$\ln IND_t$	−3.382**	−4.080**	−6.865***	−7.236***	–
$\ln SER_t$	−6.988***	−6.912***	−7.633***	−7.229***	*I*(1)
$\ln AGR_t$	−8.152***	−8.062***	−8.227***	−8.125***	*I*(1)
$\ln URB_t$	−2.069	−1.058	−1.865	−1.215	–

The PP and ADF test equations include both trend and constant terms. Schwarz information criterion (SIC) is utilized to find the optimal lag order from the ADF. The values in parentheses are consistent *p* values

***,** and *Represent significance at the 1%, 5%, and 10% levels, respectively

Table 4 ARDL bound test estimation results

Model estimation	Lag length	F-statistics	Significance level (%)	Critical (values) bound, F-statistics I(0) and I(1)
F_{CO_2}(EG|EC|FD|IND|SER|AGR|UR)	2	7.47	1	4.42 and 6.25
			5	3.20 and 4.54
			10	2.66 and 3.83

***,** and *Denote significance at the 1%, 5%, and 10% levels, respectively. All the critical values (both upper bound and lower bound) are attained from Narayan's (2005) table (e.g. Case III: Unrestricted intercept and no trend, p. 1988)

Table 5 Estimated long-run coefficients following on SBC

Regressors	Coefficients	t-ratio (p values)
Constant	5.767*	1.783 (0.085)
$\ln EG_t$	− 1.257***	− 4.419 (0.000)
$\ln EC_t$	1.531***	6.176 (0.000)
$\ln FD_t$	− 0.005	− 0.088 (0.930)
$\ln IND_t$	− 0.270	− 1.249 (0.221)
$\ln SER_t$	0.432*	1.909 (0.066)
$\ln AGR_t$	− 0.528**	− 2.242 (0.033)
$\ln URB_t$	5.061*	− 3.420 (0.002)

***,** and *Denote significance at the 1%, 5%, and 10% levels, respectively

tests. Nonetheless, the two variables are I (0) variables or stationary at level form includes 'industry' and 'urbanization'. One of the important aspects of the motivation to apply ARDL and examine this relationship is because this model accepts both I (0) and I (1) variables (Pesaran et al., 2001).

4.4 Long-run and short-run cointegration test

All results from ARDL cointegration tests are shown in Table 4. It is found that the assessed F-statistics (7.47) in the study findings are higher than the critical values (upper bound) as reported in the Narayan critical bound tables. This confirms that the variables have long-run relationships (e.g. they are cointegrated by ARDL), so the null hypothesis-no cointegration is rejected at the significance levels of 1%, 5%, and 10%, respectively.

Since the cointegrating correlation is established, the next step is to evaluate Eq. (2) to find the long-run coefficient outcomes (Table 5). Findings showed that economic expansion, growth, and development have a substantial negative influence on carbon emissions. Precisely, an increase of 1% of economic expansion and growth reduced carbon emissions by 1.26% in Pakistan. It indicates that economic expansion and growth of the country lead to positive environmental impacts by reducing carbon emissions. In other words, the growth of the country's economy enhances the quality of the environment at the same time. This finding agrees with that of Aye and Prosper (2017), who analysed developing countries, and Rauf et al. (2018) in the case of China. Likewise, the agricultural sector has a negative significant effect on carbon emissions. More specifically, and 1% change in agriculture reduce CO_2 emissions by 0.53%. This might be linked to improved and more efficient agricultural operations throughout the country and have made possible environmental sustainability. However, carbon emissions are positively and significantly impacted by the variables of conventional energy-based power utilization. It further emphasizes the point that a 1% change in conventional energy-based power utilization could increase carbon emissions by 1.53%. This finding mirrors that of Mirza and Kanwal (2017), who also undertook a study in Pakistan.

Services industries and urbanization have a substantial effect on carbon emissions. Precisely, the results suggested that services and urbanization could raise carbon emissions by 0.43% and 5.06%, respectively. This finding confirmed that of Sohag et al. (2017) and it means these variables have detrimental effects on environmental conditions in Pakistan. However, two variables (industry and financial development) wield no significant impact on carbon emissions. Thus, financial development and industry are not among the key determinants of carbon emissions. The short-run relationship of the variables emerges that economic expansion and growth lead to a negative significant effect on carbon emissions, thus confirming the main finding of the long-run period (Table 6). Financial development also reduces carbon emissions in the short-term, although the significance is very low so consequently the null hypothesis is refuted at the 10% significance level. However, as documented in the preceding long-run results, both conventional energy-based power utilization and urbanization have a substantial effect on carbon emissions even on a short-term basis. As theoretically expected, the error correction model (ECM) is found to be negative, less than 1, and statistically significant.

According to Banerjee et al. (1998), the ECM also reveals an element of convergence from both short-run and long-run contexts. Subsequently, the value of ECM validates the presence of a cointegrating correlation among variables. The coefficients from the error correction are 0.56 or 56% and the rate has occurred annually. In effect, it means that when there is a deviation from equilibrium, the variables would take about 56% annually to converge to their original equilibrium level.

4.5 Model diagnostic test

Model consistency and efficiency using a diagnostic test (Table 7) confirmed that the model has maintained all theoretical requirements such as serial correlation, Ramsey's

Table 6 Estimated short-run coefficients following on SBC

Regressors	Coefficients	*t*-ratio (*p* values)
$\Delta \ln CO_{2t-1}$	−0.293**	−2.322 (0.027)
$\Delta \ln EG_t$	−0.704***	−5.883 (0.000)
$\Delta \ln EC_t$	0.858***	4.923 (0.000)
$\Delta \ln FD_t$	−0.081*	−1.765 (0.087)
$\Delta \ln IND_t$	0.118	1.297 (0.204)
$\Delta \ln SER_t$	0.242	1.629 (0.113)
$\Delta \ln AGR_t$	−0.048	−0.467 (0.644)
$\Delta \ln URB_t$	2.836**	4.149 (0.018)
ECM(−1)	−0.560***	−4.006 (0.000)

***,** and *Denote significance at the 1%, 5%, and 10% levels, respectively

Table 7 The results from ARDL diagnostic test

Test statistics	LM version	*F*-version
1: Langrange multiplier test of residual serial correlation	CHSQ(1) = 3.508 [0.061]	*F*(1, 29) = 2.576 [0.119]
2: Ramsey's misspecification test	CHSQ(1) = 4.577 [0.032]	*F*(1, 29) = 3.454 [0.073]
3: Jacque-Bera test for normality	CHSQ(2) = 2.377 [0.305]	N/A
4: Autoregressive conditional heteroscedasticity	CHSQ(1) = 0.013 [0.906]	*F*(1, 41) = 0.013 [0.909]

***,** and *Denote significance at the 1%, 5%, and 10% levels, respectively

misspecification, Lagrange multiplier, and heteroscedasticity, etc. This is since we cannot reject any hypothesis, and this validates our model's efficiency and consistency.

Also, the model's stability is established by some popular test methods (Figs. 2 and 3), such as a cumulative sum of squares of recursive residuals (CUSUMSQ) and a cumulative sum of recursive residuals (CUSUM). The model remains highly stable over the sample period as the blue lines fall within the critical (values) bounds for both CUSUMSQ and CUSUM at the 5% significance level.

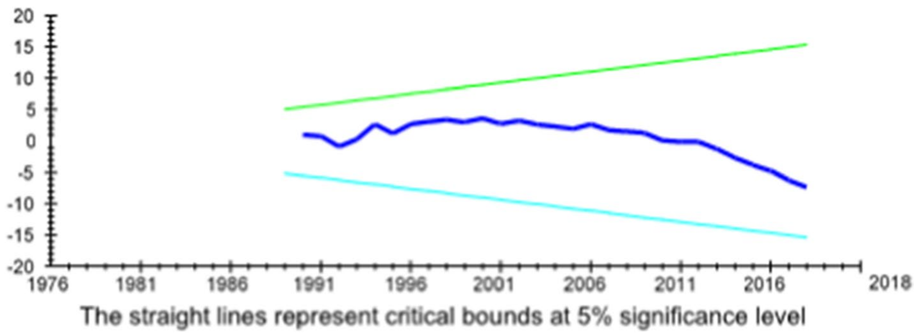

Fig. 2 Plot of cumulative sum of recursive residuals (CUSUM)

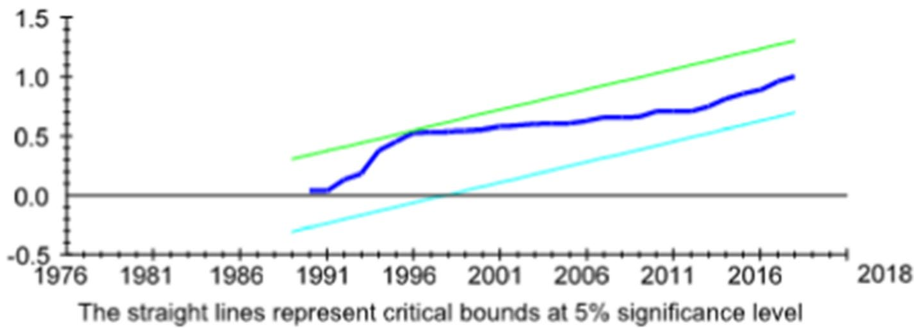

Fig. 3 Plot of cumulative sum of square of recursive residuals (CUSUMSQ)

Table 8 Results for the Johansen and Juselius cointegration test

Null hypothesis	Test statistics		Critical values (5%)	
	Trace	Max-Eigen	Trace	Max-Eigen
None	296.1756***	82.34419***	159.5297	52.36261
At most 1	213.8314***	56.57106***	125.6154	46.23142
At most 2	157.2604***	50.53950***	95.75366	40.07757
At most 3	106.7209***	37.82133**	69.81889	33.87687
At most 4	68.89955***	36.01907***	47.85613	27.58434
At most 5	32.88047**	23.02725**	29.79707	21.13162
At most 6	9.853221	7.133442	15.49471	14.26460
At most 7	2.719779	2.719779	3.841466	3.841466

***,** and *Denote significance at the 1%, 5%, and 10% levels, respectively

Table 9 Pairwise Granger causality test

Null hypothesis	Observations	*F*-Statistics	*p* value
EG does not Granger cause carbon emissions	48	5.761***	0.006
Carbon emissions do not Granger cause EG	48	1.427	0.251
EC does not Granger cause carbon emissions	48	4.813**	0.013
Carbon emissions do not Granger cause EC	48	2.471*	0.097
FD does not Granger cause carbon emissions	48	5.071***	0.010
Carbon emissions do not Granger cause FD	48	1.086	0.347
IND does not Granger cause Carbon emissions	48	5.460***	0.007
Carbon emissions do not Granger cause IND	48	2.187	0.125
SER does not Granger cause carbon emissions	48	5.875***	0.005
Carbon emissions do not Granger cause SER	48	0.642	0.531
AGR does not Granger cause carbon emissions	48	0.332	0.791
Carbon emissions do not Granger cause AGR	48	0.140	0.869
URB does not Granger cause carbon emissions	48	3.376**	0.043
Carbon emissions do not Granger cause URB	48	3.277**	0.047

***,** and *Denote significance at the 1%, 5%, and 10% levels, respectively

4.6 Model robustness check

To confirm the existence of the variables' long-term relationships, a different alternative cointegration test of Johansen and Juselius (1990) is estimated (Table 8). The variables have a long-run correlation because the values of trace statistics and max-eigen are greater than the critical value of both statistics at the 5% significance level. Hence, the Johansen and Juselius cointegration test ratifies the earlier ARDL long-run correlation among study variables, and subsequently, the main findings' consistency is validated.

A pairwise Granger causality test (Granger, 1969) was applied to validate the results were more robust and reliable and specifically about the short-run relationship (Table 9). The Granger causality outcomes disclose the existence of unidirectional causation between economic expansion and growth and development, growth, financial development, industry, services, conventional energy-based power utilization, and carbon missions. This means that these variables cause carbon missions in the long run, as we rejected the null hypothesis of no causality since all the variables' *p* values are less than 5% as theoretically expected. However, the causality between urbanization and carbon missions emerges as bidirectional, which means both variables cause each other since the *p* values of the two hypotheses are less than 5. On this basis, the hypothesis of no causal relationship is rejected at the 5% significance level.

5 Policy recommendations

This study looks at how economic growth and expansion, agriculture, services, financial development, conventional energy-based power use, industry, urbanzation, and carbon emissions all work together in Pakistan. Cointegration results (*F*-test) show that there are long-term relationships between the variables or that they are linked together. The long-term coefficient results show that both agriculture and economic growth have a big impact on carbon emissions. Liu et al. have done a similar study recently, and these findings are very similar to what they found (2017). However, several earlier studies (Sadorsky, 2014; Sheng & Guo, 2016; Wang et al., 2014; Zhang et al., 2017) found that conventional energy-based power use, services, and urbanzation have a big impact on CO_2 emissions. The short-term relationship between economic growth and carbon emissions shows how important and harmful it is. This is in line with what Bekun et al. said about the previous findings (2019).

There are three main things that are causing carbon emissions in Pakistan: conventional energy-based power, urbanzation, and financial development. Structural changes are usually the most important things that happen in different economies, and Pakistan is no exception. Changes in the structure of the economy can help to solve the problem between the environment and the economy. Pakistan's government wants to improve the country's industrial, service, and agricultural sectors, but it also wants to improve the country as a whole. This includes things like improving the country's social well-being. It would be better for the country's policymakers to encourage the development of renewable forms of conventional energy-based power, which are thought to be the key to reducing CO_2. People who have more money and people who grow food could make less carbon dioxide, but people who use renewable conventional energy-based power can also help the environment or at least cause less damage to it.

Pakistan's policymakers need to start working on effective environmental policies and conventional energy-based power-friendly techniques right away. These techniques could help improve the environment by looking into other conventional energy-based power sources. These include solar, nuclear, wind, natural gas exploration, water and hydrogen-based conventional energy-based power, and green growth, as well as other types of energy. A lot of people in the country need to pay attention to this. Carbon tax policies, subsidies, trading structures, consolidating and helping existing businesses, and encouraging new investors to put their money into competent conventional energy-based power sources could help the government avoid or prevent financial and fiscal disasters.

These things could help the government avoid or prevent financial and fiscal problems. This is an important part of changing economic policy to make the world a better place to live in the future. Pakistan's future will be bright if it switches to clean or renewable sources of power and has the right policies in place to cut down on carbon emissions. The government of Pakistan should also try to get more people to invest in green-related products and services, because the service sector is hurting the environment by releasing more carbon dioxide into the air. Furthermore, it's important to make it easier for people in rural areas to live their lives. If more people move to cities without being checked, it will cause chaos and just make more carbon dioxide. Population growth is thought to be good for an economy because it boosts both skilled and non-skilled human capital. The key is to keep the number of people living in cities under control. No species can keep growing if it runs out of the resources it needs to do so.

It's well known that conventional energy-based power can help the economy grow, but this is where the hub is. The environmental damage that comes from this nexus needs to be taken care of. This study looks at how traditional energy-based power use affects carbon emissions in Pakistan through a structural change analysis of the country. The findings of this study show how to change the way Pakistan uses traditional energy to make electricity. The carbon emission side of the study found that using carbon-rich energy resources and moving to cities will, by and large, make the environment worse by increasing carbon emissions to the maximum extent of 5.06%. However, in the long run, structural changes could make it easier to reduce carbon emissions. This would show how Pakistan's economy and agricultural production could help reduce carbon emissions. As the environment in Pakistan gets worse, this will help to fix it. However, in order to cut down on carbon emissions, policymakers should invest in renewable conventional energy sources and green-related or environmentally-friendly service-type businesses. This will help offset the emissions over the long run. Better and more effective policies should also help Pakistan's rural areas get more social amenities and infrastructure so that more people don't move to the cities, which will have less clean air and water.

6 Conclusion

This study's findings suggest structural changes in Pakistan's conventional energy-based power use. The findings on carbon emissions show that using carbon-rich energy resources and urbanzation will deteriorate the environment by increasing carbon emissions by up to 5.06%. However, structural modifications can improve carbon emission efficiency, allowing for long-term carbon emission optimization in Pakistan through economic growth and agricultural production. This will assist improve Pakistan's deteriorating environment. To offset long-term carbon emissions, policymakers should invest in renewable conventional energy sources and green-related or environmentally friendly service companies. The country's rural areas need better policies and infrastructure to avoid a population shift to urban areas, where environmental standards will be compromized.

Declarations

Conflict of interest The authors declared no such potential conflict of interest and financial involvement.

References

Abbas, S., Kousar, S., & Pervaiz, A. (2021). Effects of energy consumption and ecological footprint on CO_2 emissions: An empirical evidence from Pakistan. *Environment, Development and Sustainability, 23*(5), 13364–13381.

Abbasi, F., & Riaz, K. (2016). CO_2 emissions and financial development in an emerging economy: An augmented VAR approach. *Energy Policy, 90*, 102–114.

Abbasi, K. R., Shahbaz, M., Jiao, Z., & Tufail, M. (2021). How energy consumption, industrial growth, urbanization, and CO_2 emissions affect economic growth in Pakistan? A novel dynamic ARDL simulations approach. *Energy, 221*, 119793.

Ahmad, N., & Du, L. (2017). Effects of energy production and CO_2 emissions on economic growth in Iran: ARDL approach. *Energy, 123*, 521–537.

Akpan, G. E., & Akpan, U. F. (2012). Electricity consumption, carbon emissions and economic growth in Nigeria. *International Journal of Energy Economics and Policy, 2*(4), 292–306.

Aktar, M. A., Alam, M. M., & Al-Amin, A. Q. (2021). Global economic crisis, energy use, CO_2 emissions, and policy roadmap amid COVID-19. *Sustainable Production and Consumption, 26*, 770–781. https://doi.org/10.1016/j.spc.2020.12.029.

Alam, M. M., & Murad, M. W. (2020). The impacts of economic growth, trade openness and technological progress on renewable energy use in organization for economic co-operation and development countries. *Renewable Energy, 145*, 382–390.

Alam, M. M., Murad, M. W., Noman, A. H. M., & Ozturk, I. (2016). Relationships among carbon emissions, economic growth, energy consumption and population growth: Testing environmental Kuznets curve hypothesis for Brazil, China, India and Indonesia. *Ecological Indicators, 70*, 466–479.

Ali, H. S., Abdul-Rahim, A. S., & Ribadu, M. B. (2017a). Urbanization and carbon dioxide emissions in Singapore: Evidence from the ARDL approach. *Environmental Science and Pollution Research, 24*(2), 1967–1974.

Ali, H. S., Law, S. H., & Zannah, T. I. (2016). Dynamic impact of urbanization, economic growth, energy consumption, and trade openness on CO_2 emissions in Nigeria. *Environmental Science and Pollution Research, 23*(12), 12435–12443.

Ali, R., Bakhsh, K., & Yasin, M. A. (2019). Impact of urbanization on CO_2 emissions in emerging economy: Evidence from Pakistan. *Sustainable Cities and Society, 48*, 101553.

Ali, S., Fazal, T., Javed, F., Hafeez, A., Akhtar, M., Haider, B., ur Rehman, M. S., Zimmerman, W. B., & Rehman, F. (2020a). Investigating biodiesel production strategies as a sustainable energy resource for Pakistan. *Journal of Cleaner Production, 259*, 120.

Ali, W., Abdullah, A., & Azam, M. (2017b). The dynamic relationship between structural change and CO_2 emissions in Malaysia: A cointegrating approach. *Environmental Science and Pollution Research, 24*(12), 12723–12739.

Ali, W., Rahman, I. U., Zahid, M., Khan, M. A., & Kumail, T. (2020b). Do technology and structural changes favour environment in Malaysia: An ARDL-based evidence for environmental Kuznets curve. *Environment, Development and Sustainability, 22*(8), 7927–7950.

Anser, M. K. (2019). Impact of energy consumption and human activities on carbon emissions in Pakistan: Application of STIRPAT model. *Environmental Science and Pollution Research, 26*(13), 13453–13463.

Anwar, A., Sinha, A., Sharif, A., Siddique, M., Irshad, S., Anwar, W., & Malik, S. (2021). The nexus between urbanization, renewable energy consumption, financial development, and CO_2 emissions: Evidence from selected Asian countries. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-021-01716-2

Aqeel, A., & Butt, M. S. (2001). The relationship between energy consumption and economic growth in Pakistan. *Asia-Pacific Development Journal, 8*(2), 101–110.

Aye, G. C., & Prosper, A. E. (2017). Effect of economic growth on CO_2 emission in developing countries: Evidence from a dynamic panel threshold model. *Cogent Economics & Finance, 5*(1), 1379–2239.

Bakhsh, K., Rose, S., Ali, M. F., Ahmad, N., & Shahbaz, M. (2017). Economic growth, CO_2 emissions, renewable waste and FDI relation in Pakistan: New evidences from 3SLS. *Journal of Environmental Management, 196*, 627–632.

Banerjee, A., Dolado, J., & Mestre, R. (1998). Error-correction mechanism tests for cointegration in a single-equation framework. *Journal of Time Series Analysis, 19*(3), 267–283.

Bayar, Y., & Maxim, A. (2020). Financial development and CO_2 emissions in post-transition European Union countries. *Sustainability, 12*(7), 2640.

Bekun, F. V., Emir, F., & Sarkodie, S. A. (2019). Another look at the relationship between energy consumption, carbon dioxide emissions, and economic growth in South Africa. *Science of the Total Environment, 655*, 759–765.

Bilgili et al. (2016). Shafiei and Salim, 2014; Lozano and Gutierrez, 2008; Ajmi et al., 2015; Szklo and Schaeffer, 2007; Yin et al., 2015

Bui, D. T. (2020). Transmission channels between financial development and CO_2 emissions: A global perspective. *Heliyon, 6*(11), e05509.

Chen, P., Chen, S., Hsu, C., & Chen, C. (2016). Modeling the global relationships among economic growth, energy consumption and CO_2 emissions. *Renewable and Sustainable Energy Reviews, 65*, 420–431.

Cole, M. A. (2004). Trade, the pollution haven hypothesis and the environmental Kuznets curve: Examining the linkages. *Ecological Economics, 48*, 71–81.

Danish, Z. B., Wang, B., & Wang, Z. (2017). Role of renewable energy and non-renewable energy consumption on EKC: Evidence from Pakistan. *Journal of Cleaner Production, 156*, 855–864. https://doi.org/10.1016/j.jclepro

de Vries, G. J., & Ferrarini, B. (2017). What accounts for the growth of carbon dioxide emissions in advanced and emerging economies? The role of consumption, technology and global supply chain participation. *Ecological Economics, 132*, 213–223.

Fosu, O. E., & Magnus, F. J. (2006). Bound Testing Approach to Cointegration: An Examination of Foreign Direct Investment Trade and Growth Relationships. *American Journal of Applied Sciences 3*, 2079–2085.

Ge, J., Lei, Y., Xu, Q., & Wang, X. (2016). Sectoral roles in greenhouse gas emissions and policy implications for energy utilization and carbon emissions trading: A case study of Beijing, China. *Springerplus, 5*(1), 12–86.

Ghosh, S. (2010). Examining carbon emissions economic growth nexus for India: A multivariate cointegration approach. *Energy Policy, 38*(6), 3008–3014.

Gokmenoglu, K., Ozatac, N., & Eren, B. M. (2015). Relationship between industrial production, financial development and carbon emissions: The case of Turkey. *Procedia Economics and Finance, 25*, 463–470.

Gokmenoglu, K. K., & Sadeghieh, M. (2019). Financial development, CO_2 emissions, fossil fuel consumption and economic growth: the case of Turkey. *Strategic Planning for Energy and the Environment, 38*(4), 7–28.

Granger, C. W. J. (1969). Investigating causal relations by econometric models and cross spectral methods. *Econometrica, 37*(3), 424–438.

Grossman, G. M., & Krueger, A. B. (1993). *Environmental impacts of a North American free trade agreement, the US–Mexico free trade agreement*. MIT Press.

Heidari, H., Katircioğlu, S. T., & Saeidpour, L. (2015). Economic growth, CO_2 emissions, and energy consumption in the five ASEAN countries. *International Journal of Electrical Power & Energy Systems, 64*, 785–791.

Heil, M. T., & Selden, T. M. (1999). Panel stationarity with structural breaks: Carbon emissions and GDP. *Applied Economics Letters, 6*(4), 223–225.

Hussain, M., Irfan Javaid, M. I., & Drake, P. R. (2012). An econometric study of carbon dioxide (CO_2) emissions, energy consumption, and economic growth of Pakistan. *International Journal of Energy Sector Management, 6*(4), 518–533.

International Energy Agency. (2019). *Global energy & CO2 status report 2018: The latest trends in energy and emissions in 2018*. IEA.

Jan, I., Durrani, S. F., & Khan, H. (2021). Does renewable energy efficiently spur economic growth? Evidence from Pakistan. *Environment, Development and Sustainability, 23*(1), 373–387.

Javid, M., & Sharif, F. (2016). Environmental Kuznets curve and financial development in Pakistan. *Renewable and Sustainable Energy Reviews, 54*, 406–414.

Johansen, S., & Juselius, K. (1990). Maximum likelihood estimation and inference on cointegration–with applications to the demand for money. *Oxford Bulletin of Economics and Statistics, 52*, 169–210.

Khan, H., Weili, L., & Khan, I. (2021). Environmental innovation, trade openness and quality institutions: An integrated investigation about environmental sustainability. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-021-01590-y

Khan, M. I., Teng, J. Z., & Khan, M. K. (2020a). The impact of macroeconomic and financial development on carbon dioxide emissions in Pakistan: Evidence with a novel dynamic simulated ARDL approach. *Environmental Science and Pollution Research, 27*(31), 39560–39571.

Khan, M. K., Khan, M. I., & Rehan, M. (2020b). The relationship between energy consumption, economic growth and carbon dioxide emissions in Pakistan. *Financial Innovation, 6*(1), 1–13.

Khan, M. K., Teng, J. Z., & Khan, M. I. (2019a). Effect of energy consumption and economic growth on carbon dioxide emissions in Pakistan with dynamic ARDL simulations approach. *Environmental Science and Pollution Research, 26*(23), 23480–23490.

Khan, M. K., Teng, J. Z., Khan, M. I., & Khan, M. O. (2019b). Impact of globalization, economic factors and energy consumption on CO_2 emissions in Pakistan. *Science of the Total Environment, 688*, 424–436.

Lahiani, A. (2018). Revisiting the growth-carbon dioxide emissions nexus in Pakistan. *Environmental Science and Pollution Research, 25*(35), 35637–35645.
Liu, X., Zhang, S., & Bae, J. (2017). The impact of renewable energy and agriculture on carbon dioxide emissions: Investigating the environmental Kuznets curve in four selected ASEAN countries. *Journal of Cleaner Production, 164*, 1239–1247.
Mercan, M., & Karakaya, E. (2015). Energy consumption, economic growth and carbon emission: Dynamic panel cointegration analysis for selected OECD countries. *Proceedings of Economic Finance, 23*, 587–592.
Mirza, F. M., & Kanwal, A. (2017). Energy consumption, carbon emissions and economic growth in Pakistan: Dynamic causality analysis. *Renewable and Sustainable Energy Reviews, 72*, 1233–1240.
Mohsin, M., Kamran, H. W., Nawaz, M. A., Hussain, M. S., & Dahri, A. S. (2021). Assessing the impact of transition from nonrenewable to renewable energy consumption on economic growth-environmental nexus from developing Asian economies. *Journal of Environmental Management, 284*, 111999.
Muhammad, J., & Ghulam Fatima, S. (2013). Energy Consumption, Financial development and CO_2 emissions in Pakistan. MPRA Paper No. 48287. https://mpra.ub.uni-muenchen.de/48287/1/MPRA_paper_48287.pdf.
Murad, M. W., Alam, M. M., & Islam, M. M. (2018). Dynamics of Japan's industrial production and carbon emissions: Causality, long-term trend and implications. *Letters in Spatial and Resource Sciences, 11*(2), 127–139.
Murad, M. W., Alam, M. M., Noman, A. H. M., & Ozturk, I. (2019). Dynamics of technological innovation, energy consumption, energy price and economic growth in Denmark. *Environmental Progress & Sustainable Energy, 38*(1), 22–29.
Nasrollahi, Z., Hashemi, M. S., Bameri, S., & Taghvaee, V. M. (2020). Environmental pollution, economic growth, population, industrialization, and technology in weak and strong sustainability: Using STIRPAT model. *Environment, Development and Sustainability, 22*(2), 1105–1122.
Nayyar, Z. A., Zaigham, N. A., & Qadeer, A. (2014). Assessment of present conventional and non-conventional energy scenario of Pakistan. *Renewable and Sustainable Energy Reviews, 31*, 543–553.
Nehrenheim, E. (2013). Energy and natural resources: Introductory article. *Reference Module in Earth Systems and Environmental Sciences*, pp. 441–449.
Nejat, P., Jomehzadeh, F., Taheri, M. M., Gohari, M., & Majid, M. Z. A. (2015). A global review of energy consumption, CO_2 emissions and policy in the residential sector (with an overview of the top ten CO_2 emitting countries). *Renewable and Sustainable Energy Reviews, 43*, 843–862.
Panayotou, T. (1993). *Empirical tests and policy analysis of environmental degradation at different stages of economic development* (No. 992927783402676). International Labour Organization.
Paramati, S. R., Alam, M. S., & Chen, C. F. (2017). The effects of tourism on economic growth and CO_2 emissions: A comparison between developed and developing economies. *Journal of Travel Research, 56*(6), 712–724.
Pesaran, M. H. (1997). The role of economic theory in modelling the long run. *The Economic Journal, 107*(440), 178–191.
Pesaran, M. H., & Pesaran, B. (1997). *Working with Microfit 4.0*. Cambridge: Camfit Data Ltd.
Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics, 16*(3), 289–326.
Petrović, P., & Lobanov, M. M. (2021). Impact of financial development on CO_2 emissions: Improved empirical results. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-021-01721-5
Ramanathan, R. (2002). Combining indicators of energy consumption and CO_2 emissions: A cross-country comparison. *International Journal of Global Energy Issues, 17*(3), 214–227.
Rauf, A., Zhang, J., Li, J., & Amin, W. (2018). Structural changes, energy consumption and carbon emissions in China: Empirical evidence from ARDL bound testing model. *Structural Change and Economic Dynamics, 47*, 194–206.
Raza, M. Y., & Shah, M. T. S. (2020). Analysis of coal-related energy consumption in Pakistan: An alternative energy resource to fuel economic development. *Environment, Development and Sustainability, 22*(7), 6149–6170.
Rehman, A., Ullah, I., Afridi, F. E. A., Ullah, Z., Zeeshan, M., Hussain, A., & Rahman, H. U. (2021). Adoption of green banking practices and environmental performance in Pakistan: A demonstration of structural equation modelling. *Environment, Development and Sustainability, 23*(9), 13200–13220.
Sadorsky, P. (2014). The effect of urbanization on CO_2 emissions in emerging economies. *Energy Economics, 41*, 147–153.

Salahuddin, M., Ali, M. I., Vink, N., & Gow, J. (2019). The effects of urbanization and globalization on CO_2 emissions: evidence from the Sub-Saharan Africa (SSA) countries. *Environmental Science and Pollution Research, 26*(3), 2699–2709.

Saleem, H., Khan, M. B., & Shabbir, M. S. (2020). The role of financial development, energy demand, and technological change in environmental sustainability agenda: Evidence from selected Asian countries. *Environmental Science and Pollution Research, 27*(5), 5266–5280.

Selden, T. M., & Song, D. (1994). Environmental quality and development: Is there a Kuznets curve for air pollution emissions? *Journal of Environmental Economics and Management, 27*(2), 147–162.

Shahbaz, M., Loganathan, N., Muzaffar, A. T., Ahmed, K., & Jabran, M. A. (2016). How urbanization affects CO_2 emissions in Malaysia? The application of STIRPAT model. *Renewable and Sustainable Energy Reviews, 57*, 83–93.

Shahbaz, M., Solarin, S. A., Mahmood, H., & Arouri, M. (2013a). Does financial development reduce CO_2 emissions in Malaysian economy? A time series analysis. *Economic Modelling, 35*, 145–152.

Shahbaz, M., Solarin, S. A., Mahmood, H., & Arouri, M. (2013b). Does financial development reduce CO_2 emissions in Malaysian economy? A time series analysis. *Economic Modelling, 35*, 145–152.

Sharma, R., Sinha, A., & Kautish, P. (2021). Does renewable energy consumption reduce ecological footprint? Evidence from eight developing countries of Asia. *Journal of Cleaner Production, 285*, 124867.

Sheng, P., & Guo, X. (2016). The long-run and short-run impacts of urbanization on carbon dioxide emissions. *Economic Modelling, 53*, 208–215.

Siddique, H. M. A. (2017). Impact of financial development and energy consumption on CO_2 emissions: Evidence from Pakistan. *Bulletin of Business and Economics, 6*(2), 68–73.

Sohag, K., Al Mamun, M., Uddin, G. S., & Ahmed, A. M. (2017). Sectoral output, energy use, and CO_2 emission in middle-income countries. *Environmental Science and Pollution Research, 24*(10), 9754–9764.

Taghvaee, V. M., Mavuka, C., & Shirazi, J. K. (2017). Economic growth and energy consumption in Iran: An ARDL approach including renewable and non-renewable energies. *Environment, Development and Sustainability, 19*(6), 2405–2420.

Umar, B., Alam, M. M., & Al-Amin, A. Q. (2021). Exploring the contribution of energy price to carbon emissions in African countries. *Environmental Science and Pollution Research, 28*(2), 1973–1982.

Villanthenkodath, M. A., Ansari, M. A., Shahbaz, M., & Vo, X. V. (2021). Do tourism development and structural change promote environmental quality? Evidence from India. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-021-01654-z

Wang, Q., Wu, S. D., Zeng, Y. E., & Wu, B. W. (2016a). Exploring the relationship between urbanization, energy consumption, and CO_2 emissions in different provinces of China. *Renewable and Sustainable Energy Reviews, 54*, 1563–1579.

Wang, S., Fang, C., Guan, X., Pang, B., & Ma, H. (2014). Urbanisation, energy consumption, and carbon dioxide emissions in China: A panel data analysis of China's provinces. *Applied Energy, 136*, 738–749.

Wang, S., Li, Q., Fang, C., & Zhou, C. (2016b). The relationship between economic growth, energy consumption, and CO_2 emissions: Empirical evidence from China. *Science of the Total Environment, 542*, 360–371.

Weimin, Z., Chishti, M. Z., Rehman, A., & Ahmad, M. (2021). A pathway toward future sustainability: Assessing the influence of innovation shocks on CO_2 emissions in developing economies. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-021-01634-3

Winfield, M., & Dolter, B. (2014). Energy, economic and environmental discourses and their policy impact: The case of Ontario′ s Green energy and green economy act. *Energy Policy, 68*, 423–435.

World Bank. (2018), The World Bank Home Page. Available online: https://data.worldbank.org. Accessed on 27 September 2018.

World Bank. (2019). The World Bank Home Page. Available online: https://data.worldbank.org. Accessed on 15 December 2019.

Wu, Y., Zhu, Q., & Zhu, B. (2018). Decoupling analysis of world economic growth and CO_2 emissions: A study comparing developed and developing countries. *Journal of Cleaner Production, 190*, 94–103.

Xing, T., Jiang, Q., & Ma, X. (2017). To facilitate or curb? The role of financial development in China's carbon emissions reduction process: A novel approach. *International Journal of Evironmental Research and Public Health, 14*(10), 12–22.

Yasin, I., Ahmad, N., & Chaudhary, M. A. (2021). The impact of financial development, political institutions, and urbanization on environmental degradation: Evidence from 59 less-developed economies. *Environment, Development and Sustainability, 23*(5), 6698–6721.

Zaidi, S. A. H., Hou, F., & Mirza, F. M. (2018). The role of renewable and non-renewable energy consumption in CO_2 emissions: A disaggregate analysis of Pakistan. *Environmental Science and Pollution Research, 25*(31), 31616–31629.

Zaidi, S. A. H., Zafar, M. W., Shahbaz, M., & Hou, F. (2019). Dynamic linkages between globalization, financial development and carbon emissions: Evidence from Asia Pacific Economic Cooperation countries. *Journal of Cleaner Production, 228*, 533–543.

Zhang, B., Wang, Z., & Wang, B. (2018). Energy production, economic growth and CO_2 emission: Evidence from Pakistan. *Natural Hazards, 90*(1), 27–50.

Zhang, N., Yu, K., & Chen, Z. (2017). How does urbanization affect carbon dioxide emissions? A cross-country panel data analysis. *Energy Policy, 107*, 678–687.

Zhang, Y.-J. (2011). The impact of financial development on carbon emissions: An empirical analysis in China. *Energy Policy, 39*(4), 2197–2203.

Zhu, H. M., You, W. H., & Zeng, Z. F. (2012). Urbanization and CO_2 emissions: A semi-parametric panel data analysis. *Economics Letters, 117*(3), 848–850.

Authors and Affiliations

Hamisu Sadi Ali[1] · Malayaranjan Sahoo[2] · Md. Mahmudul Alam[3] · Idris Isma'il Tijjani[4] · Abul Quasem Al-Amin[5,6,8] · Adeel Ahmed[7]

Hamisu Sadi Ali
hamisusadi@gmail.com

Malayaranjan Sahoo
sahoomalayaranjan4@gmail.com

Idris Isma'il Tijjani
ismaildel@yahoo.com

Abul Quasem Al-Amin
qalamin@uwaterloo.ca

Adeel Ahmed
adeelawan261@gmail.com

1 Department of Economics, ABU Business School, Ahmadu Bello University, Zaria, Kaduna, Nigeria

2 Department of Humanities and Social Sciences, National Institute of Technology (NIT), Rourkela, Odisha, India

3 Economic and Financial Policy Institute (ECoFI), School of Economics, Finance and Banking (SEFB), Universiti Utara Malaysia (UUM), 06010 Sintok, Kedah, Malaysia

4 Department of Banking and Finance, ABU Business School, Ahmadu Bello University, Zaria, Kaduna, Nigeria

5 Department of Geography and Environmental Management, University of Waterloo, Waterloo, ON, Canada

6 Centre for Asian Climate and Environmental Policy Studies, 1525 University Avenue West, Windsor, ON, Canada

7 Department of IB&M, Business School, National University of Sciences and Technology, Islamabad, Pakistan

8 Department of Development Studies, Daffodil International University, Dhaka, Bangladesh