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Looking for asymmetries and nonlinearities: The nexus between renewable energy and environmental degradation in the Northwestern provinces of China

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ABSTRACT

Recent industrial surge in the Northwestern provinces of China resulted in substantial energy consumption and adverse effect on the environment. Despite being less established, the Northwestern region of China has strategic importance and the use of renewable energy can potentially promote sustainable development in this region. Considering this aspect, this study aims to investigate the impact of renewable energy on environmental pollution in five Northwestern provinces of China during 1995–2014. This study uses the Nonlinear Autoregressive Distributed Lag bounds testing approach with the structural break unit root and other specifications tests. The results indicate that renewable energy positive shock has an adverse impact on the CO_2 emissions of the Northwestern provinces of China. The effect of renewable energy use varies in five provinces, i.e. it is more significant in Gansu, Qinghai and Xinjiang than in Ningxia and Shaanxi. However, reduction in renewable energy consumption leads to higher level of CO_2 emissions and this effect is more significant for Ningxia and Shaanxi in the long run. Furthermore, the positive shockwaves in nonrenewable energy, GDP and transportation are associated with environmental pollution in these provinces both in short run and long run. Nevertheless, the impact of negative shockwaves in nonrenewable energy consumption on environmental pollution is more significant than economic development for all provinces. Our findings suggest that: cutting down fossil fuels use can substantially improve environmental quality in these provinces; depending on the provincial geographies and government strategies, the intensity of positive impact of renewable energy towards CO_2 emissions reduction differs among five provinces. Likewise, renewable energy development has abundant potential to increase the economic and ecological sustainability in the Northwestern provinces of China in the long run.

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1. Introduction

Due to rapid industrialization and urbanization, the world has witnessed an outstanding level of economic development during the last few decades. The World Bank statistics indicate that global GDP increased from $37.224 trillion to $72.247 trillion from 1990 to 2014. As a result, the total energy consumption also increased with rapid rates in the world. The British Petroleum (BP) data indicates that global energy consumption increased from 8.133 billion tons to 12.928 billion tons of oil equivalent from 1990 to 2014. Similarly, fossil fuel based global Carbon Dioxide (CO_2) emissions increased from 22.7 to 35.5 billion tons for the same period (Dong et al., 2018). Fossil fuels are the main energy source and a significant contributor to CO_2 emissions at present. Petroleum related byproducts are considered as the utmost imperative fuels utilized in numerous walks of life to promote overall development. Conversely, the ignition of gasoline and its byproducts perform an important part

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in the present experience of global warming. In 2015, the share of petroleum associated CO_2 emissions reached 34.6% of overall CO_2 emissions produced due to energy consumption in the world (Liu et al., 2019a,b,c). The BP predictions indicate that fuel will remain the main source of worldwide crucial energy; it will substitute coal and become the leading source of CO_2 emissions all over the world by the year 2035 (BP, 2018).

Global warming and climate change are the major concerns of both developing and advanced countries around the globe. The growing greenhouse gas emissions, in the form of temperature level variations and vulnerable weather conditions, have led to some severe environmental consequences. Generally, rapid growth of manufacturing sector is blamed for environmental pollution in developing and advanced economies. The aforementioned environmental changes demand serious policy measures from various stakeholders to reduce CO_2 emissions and to protect the national economy and environment. The extensive energy consumption is a major reason of environmental concerns and can lead to the scarcity of natural resources. The shift from traditional to alternative renewable energy sources is necessary to promote environmental-friendly economic development. To deal with the environmental concerns, 195 countries of the world signed the Paris agreement to reduce the temperature up to a significant level and to promote green development (Moutinho et al., 2018). The increasing CO_2 emissions from human activities and financial development are considered the main factors of environmental issues. The agenda of sustainable development aims to limit the worldwide temperature to deal with the serious problem of global warming. In view of this, to promote sustainable development, international community is shifting its focus towards decarbonization through clean energy (Pao and Chen, 2019).

Renewable energy experienced a record breaking increase in terms of increased power capacity, decreasing costs, significant investment and developments in supporting technologies. Recently, many developed countries have started focusing on electrification of transport, amassing digitalization and taking new initiatives to become coal-free energy producers (Sharif et al., 2019). Renewable power sector continued to grow at significant rates worldwide, and the total share of renewable energy in total consumption accounted for 18.2% during 2016; moreover, renewable power generation capacity increased with 9% and renewables accounted for almost 70% of the entire increase in total capability of power capacity during 2017. The net investment in renewable energy and fuel accounted for $280 billion in 2017. From 2016 to 2017, the renewable power capacity increased from 2017 Gigawatt (GW) to 2195 GW (REN21, 2018). In addition to this, several countries are shifting from traditional sources of energy to green energy production; during 2017, 179 countries set less CO_2 emission targets by using renewable energy sources at the state, provincial and national levels (REN21, 2018). Since the last decade, China experienced remarkable economic growth and became the second largest economy after the United States. The prominent factors of this rapid growth include trade, investment and a huge labor market. However, this rapid growth led to immense energy consumption and energy related CO_2 emissions, making China a leading CO_2 emitter around the globe (Wang and Jiang, 2019).

China's rapid financial and social growth led to an increase of petroleum products consumption; currently, China is the second main petroleum user and the second highest in terms of petroleum-related CO_2 emissions. China contributed an addition of nearly 37% to global petroleum products consumption from 1990 to 2016 and experienced 4.3 times increase in total consumption (IEA, 2017). Having a vast territory, different parts of China show significant variations in terms of economic development, population growth and energy consumption. The shift of resources from its eastern region to relatively poor Northwestern region is associated with massive CO_2 emissions. The BP data shows that China's fossil fuel emissions reached up to 9.123 billion tons, i.e. 29.23% of the total emissions during 2016. As a responsible developing nation, China initiated various policy measures to reduce its CO_2 emissions; one of these actions is the China's commitment to reduce CO_2 intensity up to 60%–65% till 2030 as compared to its emissions level of 2005. Similarly, China assured to raise its part of non-fossil fuels in overall energy use up to 20% till 2030. To address the emission issue in the long run, these measures indicate the efforts of Chinese government in promoting renewable energy sources (Wang et al., 2018). As the biggest power user and CO_2 producer, China has recently been applying the renewable energy strategy to deal with environmental degradation problems. Its non-coal energy capacity is developing rapidly; a series of policies emphasize on forming alternative energy sources and establishing an advanced system to supply the energy produced from various traditional and renewable energy supply sources. China's installed capacity of renewable energy reached to 650 million kWh and the total yearly energy production capacity reached to 1.7 trillion kWh (Yu et al., 2019). As of the end of 2017, the share of renewable energy reached to the 26.4% of the overall energy production (CNEA, 2018).

The Northwestern provinces of China are considered relatively poor than the central and eastern provinces in financial terms. These provinces also face various environmental issues due to less water availability and arid climate. Considering this, Chinese government introduced various development strategies that turned into a massive economic cooperation plan recently known as the Belt and Road initiative. The increased focus had significant impacts on trade and industrial growth. However, intense environmental pressure, relatively fragile environmental condition, and the heavy and low-value-added industrial base are the main challenges of these provinces. Additionally, the substantial energy consumption amplified CO_2 emissions and added to environmental degradation (Ahmad et al., 2018). The Northwestern provinces of China have parallel level of development and similar climate characteristics. To deal with severe climate and environmental pollution, after the launch of renewable energy law, the central Chinese government is focused to increase the renewable energy consumption in these provinces; which include construction of various bases for renewable power generation to uplift the living standards of rural population and reduce the environmental pollution. On the other hand, the northwest region seeks the external investment for economic development; nevertheless, this investment always focuses on energy-consumption industries and the resulting traffic and transportation also exert adverse effect on the environment (Wu and Xu, 2013).

Considering the fragile climate and extensive fossil fuel energy consumption for economic and infrastructural development, adjustments in energy supply structure and promoting the use of renewable energy can have a worthy effect on the sustainable development of northwest provinces of China. Therefore, this study investigates the impact of renewable energy on environmental pollution of China's five Northwestern provinces namely Gansu, Qinghai, Ningxia, Shaanxi and Xinjiang during 1995–2014. The existing works emphases on the industrialized regions of China and used panel data to investigate this energy-environment nexus. The evident gap in the available literature demands a comprehensive investigation for these core provinces of the Northwestern China.

This research will contribute to the existing works by exploring the less developed provinces of a very important region. The present study is novel due to its detailed investigation of five northwest provinces to explore the energy-environment relationship on individual bases. The detailed investigation of present literature proves that this research is among the pioneer studies to

investigate this connotation using the NARDL approach for the aforementioned five provinces independently and linked the findings to stimulate their eco-friendly development by promoting the use of renewable energy. Therefore, our study offers a valuable addition to the literature as it explores symmetric and asymmetric aspect of the association concerning renewable energy and environmental pollution in the short run and long run for these provinces.

The remaining parts of this paper are structured as follows: section 2 offers the assessment of latest literature and section 3 explains the conceptual framework and elaborates the data, variables and methodology used in this study. Section 4 reports the results and associated discussions. Finally, concluding remarks and detailed policy implications are discussed in Section 5.

2. Literature review

2.1. Renewable energy use and CO_2 emissions in developed regions

Considering energy prices as possible driver, Jaforullah and King (2015) found that the CO_2 emissions are negatively related with renewable energy consumption and the link between nuclear energy use and the CO_2 emission is not significant for the USA. Comparing the elements influencing the CO_2 emission in top 23 European countries with the rest of the world Moutinho et al. (2018) confirmed that the efficiency of renewable sources and the fiscal growth influence in renewable power production and per GDP reduced CO_2 emissions. Whereas, the fossil fuel energy consumptions added to the CO_2 emissions. In addition, energy technology has an important effect on CO_2 emissions reduction. Estimating the Carbon Kuznets Curve (CKC), renewable and fossil fuels energy consumption for carbon emissions for G20 Pao and Chen (2019) confirmed the presence of CKC and a long run association among these variables. Whereas, fossil fuels energy consumption has a positive and the clean energy has an adverse effect on CO_2 emissions, respectively. Furthermore, energy saving policy may hurt the economic development but the increased share of clean energy is necessary for long term sustainable development. Examining the nexus among clean energy, economic development and CO_2 emissions for G7 Cai et al. (2018) identified no co-integration among these variables in France, Italy, Canada, UK and the USA but the co-integration exist in case of Japan and Germany. Besides, there exists mix causative connection between clean energy and CO_2 emissions for various countries. Using the panel of South American countries Hdom (2019) provided the evidence of a long term significant negative effect of renewable energy electricity production on the CO_2 emissions. The fossil fuels and economic development have positive impact on the environmental pollution.

2.2. Renewable energy use and CO_2 emissions in developing regions

Analyzing the role of renewable energy in the sustainable growth of Malaysia, Bekhet and Othman (2018) confirmed the existence of EKC hypothesis in Malaysia. Renewable energy helps to decrease CO_2 emission as the association between two factors is negative. Likewise, GDP growth acts as a tonic to improve ecological condition in the long run. Using the Autoregressive Distributed Lag model (ARDL) to examine the association among renewable energy, GDP growth and CO_2 emission, Cherni and Essaber Jouini (2017) revealed a stable link among three variables for Tunisia. Bidirectional causality runs from GDP, CO_2 emissions and renewable energy to GDP. However, no association is established between renewable energy and CO_2 emission. Using the ARDL method, Waheed et al. (2018) studied the connection among renewable energy consumption, agriculture production, and forest and CO_2 emissions in Pakistan. Their results confirmed that renewable energy consumption and forest decrease the CO_2 emissions and the agriculture production is the main source of CO_2 emissions. Overall, plantation is more effective to improve the environment than the renewable energy. Examining the CO_2 emission from power sector of Pakistan, Lin and Raza (2019) cited that the population growth, GDP growth related activities are the main source of increased omission. Nevertheless, the use of clean energy in power sector can significantly reduce the energy related emission in future. Estimating the EKC for CO_2 emission in India, Sinha and Shahbaz (2018) found the indication of EKC and the significant negative influence of renewable energy on CO_2 emission. Moreover, the long run elasticity of overall energy consumption is higher than the short run.

Using the data of 42 developing countries, Ito (2017) examined CO_2 emissions, energy and growth nexus. The results confirmed that renewable energy has a positive effect and non-renewable energy has a negative influence on economic growth in the long run. Using the dataset of 128 countries, Dong et al. (2018) inspected the link among CO_2 emissions, economic and population growth, and renewable energy and suggested that population size and economic development considerably affects CO_2 emissions at international and regional level. The renewable energy use led to the lower CO_2 emissions in all regions with variations among them. Additionally, the estimations also validated the causal links among these variables across the regions. Exploring the connection of renewable and non-renewable energy consumption with CO_2 emission for 74 countries, Sharif et al. (2019) concluded a long run association among variables. Furthermore, financial development and renewable energy significantly reduce the environmental pollution; however, the non-renewable energy degrades the environment. likewise, the results of DOLS and FMOLS for 17 main developing and advanced nations confirmed CO_2 emissions reduction with renewable energy (Yao et al., 2019). Exploring this nexus with GMM, Hanif et al. (2019) also found that renewable energy reduced CO_2 emission in Asia. Furthermore, resource depletion and population is positively associated with emissions. However, this impact varies among different countries according to their income level and stages of development. Renewable energy associated with less CO_2 emissions for developed nations, and accelerates this level in developing countries (Nguyen and Kakinaka, 2019). Employing the panel vector autoregressive (PVAR) model, Charfeddine and Kahia (2019) examined the impact of financial development and renewable energy on economic growth and CO_2 emissions in MENA countries. The results suggested weak link among the variables. This indicates that renewable energy and financial development sectors need further improvements to contribute in the environmental and economic development for this region. Using the OLS and GMM Adams and Nsiah (2019) concluded that both renewable and traditional energy use increase CO_2 emissions in 28 African nations. However, the impact of nonrenewable energy is significant in short run. Addressing the determinants of CO_2 emissions in Sub-Saharan Africa, Inglesi-Lotz and Dogan (2018) confirmed a long run association among energy, income, trade and CO_2. The positive effect of non-renewable energy and a negative effect of renewable energy on CO_2 held constant, respectively in the long run. Likewise, the direction of causality varied among all determinants. Inspecting the nexus among CO_2 emissions, GDP and natural gas and renewable energy consumption within the EKC framework Dong et al. (2017) suggested that the EKC holds in the BRICS countries. The increased renewable energy and natural gas use reduces the CO_2 emissions. Furthermore, the feedback causal connection holds among these variables in the long run.

2.3. Renewable energy use and CO_2 emissions in Chinese regions

The CO_2 associated environmental issues have been intensively investigated with the help of different statistical methods for many regions in the world. Using co-integration approach for China energy environment nexus, Long et al. (2015) stated a significant impact of nonrenewable energy on environment. Yet, the role of renewable energy is crucial to decrease this effect in the long run. Testing the environmental Kuznets curve (EKC), Dong et al. (2018) suggested that the natural gas and renewable energy consumption reduce the CO_2 emission level for both long and short run as well as validate the EKC hypothesis in China. Additionally, the role of renewable energy in CO_2 emission mitigation is significant than the natural gas. Exploring the dynamic causal links among CO_2, GDP, nuclear energy consumption, fossil fuels consumption and renewable energy consumption per capita for China, Dong et al. (2018) established the presence of the EKC. The renewable and nuclear energy significantly in mitigate CO_2 emissions, whereas fossil fuels consumption promotes CO_2 emissions. Additionally, the impact of renewable energy is significant than the nuclear energy to reduce the CO_2 emission.

Exploring the relationship CO_2 emissions, GDP, renewable, non-renewable energy production and foreign trade for China Chen et al. (2019) found a long run connection among these factors but no evidence of EKC. The addition of foreign trade and renewable energy provide substantial reduction in CO_2 emissions and the validity of EKC in the long run. Likewise, bidirectional causality runs from all variables to renewable energy. Using the Computable General Equilibrium (CGE) model Xie et al. (2018) investigated the connection between renewable energy and CO_2 emission for the most severely polluted Jing-Jin-Ji region of China. The results supported that both renewable energy and SO2 taxation reduce the CO_2 emission. However, the influence of renewable energy is more significant than the taxation in Hebei and the tax policy is also suitable to decrease the CO_2 emission in Tianjin. Furthermore, the Beijing and Tianjin will suffer a greater economic loss than Hebei from this CO_2 emission control policy. Analyzing the contribution of non-fossil fuels to CO_2 emission reduction from 30 Chinese provinces, Wang et al. (2019) concluded that 1% escalation in the use of non-fossil fuels reduces the 2% electricity related emission. However, the impact is more obvious for the post-reform period supporting that the renewable energy sources improve the environment in different Chinese regions.

Applying an advanced version of input-output model, Liu et al., 2019a,b,c suggested that cleaner production mitigated emissions level among Chinese provinces. Similarly, economic structure also contributed towards CO_2 emissions in China. The input-output model described that emissions from demand and supply side varies among different industries in China, and manufacturing sector still leads in this regard (T. Jiang et al., 2019). Likewise, measuring the regional and sectorial emissions spillover with input-output model, Ning et al. (2019) identified a significant interregional impact. The production spillovers are at the top and also the distance among Chinese provinces matters for emissions level. Exploring the link between energy consumption and CO_2 emissions, Chen et al. (2019) suggested that the EKC hypothesis was not held in the central and western regions and was hardly sustained in the eastern region. The non-renewable energy adverse impact was most significant in central, western and eastern region, respectively. Whereas, renewable energy reduced the CO_2 emissions in western and eastern regions and the impact was insignificant in central region of China. Furthermore, the direction of short and long run causal association was mixed among various regions.

The current literature clearly indicates that the use of alternative clean energy and healthy ecological conditions are crucial for sustainable development. Similarly, it informs about the threats associated with increased environmental degradation due to economic and infrastructural development related energy consumption and eventual carbon emission. At present, typically available studies ponder the advanced countries and regions using the panel data. Most of studies in literature used traditional regression techniques. Also, used panel data and carried the investigation on macro level. This clearly indicates that the endogeneity of findings in previous literature, the defects of empirical models, and the heterogeneity of cases demands a fresh micro level study with relative strong technique to investigate this association. Furthermore, most of previous studies applied conventional ARDL and did not consider the positive and negative shock effect. Thus, the individual investigation of less developed northwest Chinese provinces will be a novel contribution to the literature.

3. Study context, data, variables and methodology

The fossil fuels are the main energy source all over the world as well as a significant contributor to the CO_2 emissions (Ahmad et al., 2019). Petroleum and its byproducts considered as the most imperative fuels and biochemical raw resources utilized in numerous fiscal and public fields. Recently, the focus of many countries has shifted towards sustainable development and use of modern measures to promote green economic development have already adopted in many regions. China is the large country with rapid economic development and massive energy consumption to main the high economic growth rates. Thus, the use of alternative energy means is necessary to maintain the sustainable economic development (Moutinho et al., 2018). As a major player of international market, China has committed to mitigate the CO_2 emissions to protect the environment and promote green economic development.

The Chinese government has been focusing to produce energy from environmental friendly alternative resources to decrease the environmental pollution in various regions. As a result, the installation capacity of renewable energy has been increasing in all over China during the recent years (Wang et al., 2018). Similarly, China possesses a large territory with significant regional alterations about its socioeconomic growth and environmental effects and the level of development varies among different regions.

Since last three decades, the energy consumption and economic development increased in many parts of China. The northwest region is lagging behind in terms of economic development but these provinces are strategically very important due to Belt and Road initiative. This initiative helps to realize the unknown beauty of this region and introduces alternative aspects for ecological development with renewable energy use. The coal centered industrial growth and energy use significantly weakened the natural atmosphere in Northwestern region and the government has been focusing to introduce different environmental friendly energy sources to reduce the pollution in northwest region. Fig. 1 specifies that the use of renewable energy is significant in Gansu during 1995. Similarly, renewable energy consumption is relatively small in Qinghai and Shaanxi than in Gansu. Whereas, the level of renewable energy use is much lower in Xinjiang and Ningxia at the start. Fig. 2 represents the energy consumption for five provinces during 2014. All else being equal, Gansu maintained the significant energy consumption. A noticeable increase can be observed in Qinghai and Xinjiang but this increase is more significant for Qinghai. On the other hand, Shaanxi experienced a decrease and Ningxia followed the similar pattern in terms of green energy consumption in 2014.

Figs. 3 and 4, represents the CO_2 emissions for specific region during 1995 and 2014 respectively. Qinghai and Ningxia are

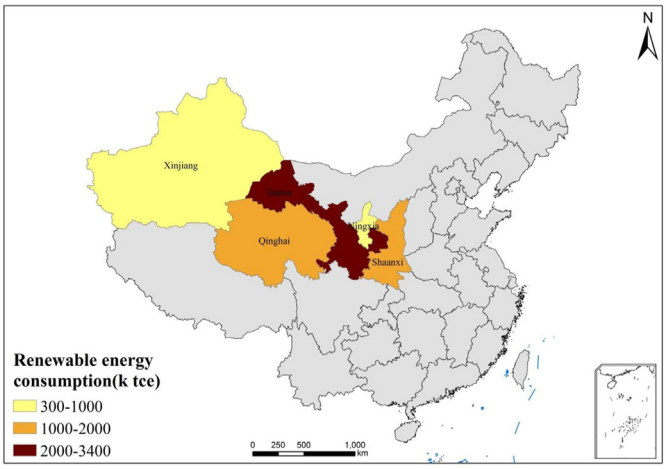

Fig. 1. Renewable energy consumption in five provinces in 1995.

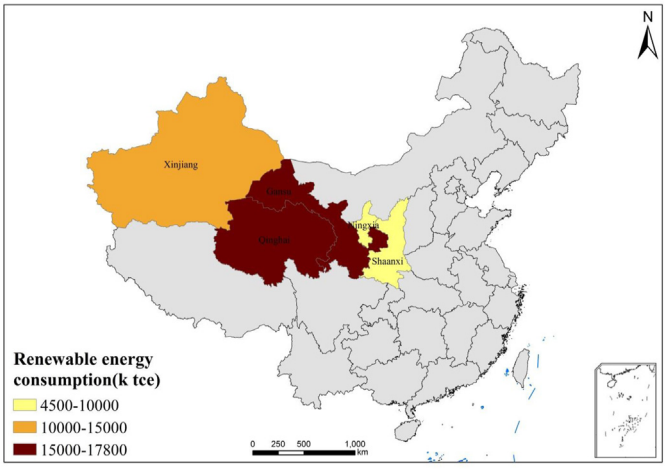

Fig. 2. Renewable energy consumption in five provinces in 2014.

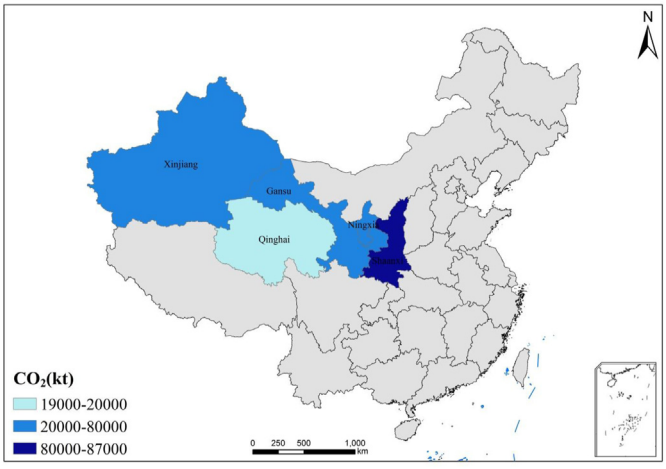

Fig. 3. CO_2 emissions in five provinces in 1995.

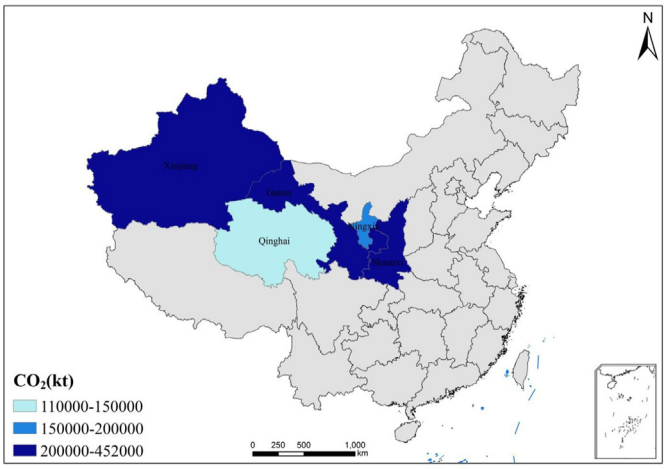

Fig. 4. CO_2 emissions in five provinces in 2014.

consistently producing less CO_2 than the remaining provinces. There are significant variations in the emissions among all provinces. For example, the total emissions have been growing during the study period, but Xinjiang, Gansu and Shaanxi are the main contributors to the CO_2 emissions than other provinces. Xinjiang and Shaanxi are ranked among the key energy producer in China. Similarly, the extensive use of energy resources for various development plans under Belt and Road also adversely affected the regional atmosphere. The industrial development has also been initiated in Xinjiang due to various Belt and Road development programs. Thus, the swift escalation of CO_2 in this area has put a significant pressure on the environment. Moreover, the increased energy consumption for economic development is also significantly polluting the environment in Xinjiang (Ahmad et al., 2018). Additionally, the renewable energy consumption policies and the implementation is unequal among these provinces due to less economic development of the Northwestern region but promotion of green energy use and associated strategy might have substantial effect to recover the environment. Therefore, a systematic study is essential to inspect the real influence of renewable energy on environmental quality in the Northwestern region of China.

3.1. Data and variables

To investigate this relationship, the renewable energy and CO_2 emission are the main variables used in the present study. The CO_2 emission has been used as the proxy for ecological deterioration. As the provincial data is unavailable, the CO_2 values have been derived through the multiplication of emissions factors and standard consumption of traditional energy in kg. The emissions for CO_2 is calculated under a formula for CO_2 estimations; equation could be written as: $(CO2 = \sum_{i=1}^{3} \frac{E_i}{a_i}\beta_i)$, where CO_2 characterizes with CO_2 emissions; E_i symbolizes energy consumption through three sources coal, oil, and natural gas consumption; a_i designates conversion rate for energy consumption through coal, natural gas and crude oil, and β_i implies level of CO_2 emission factors for each of the three fuels. The control variables for on hand study include GDP per capita, transportation and nonrenewable energy consumption. The index of transportation is constructed using the length of roads, railways and traffic per 10000 persons. This index is constructed considering three sources of transportation. Hence, for transportation (TR), a Principal Component Analysis (PCA) index is

designed which covers; the length of railway operations, length of highways in 10000 km and passengers' traffic in 10000 persons. The data for transportation index variables are collected from China Statistical Yearbook. The value of GDP is measured as constant 2000 RMB. The data of all variables except renewable energy are collected from China Statistical Yearbook and National Bureau of Statistics of China. This study uses Non-fossil fuel consumption to represent renewable energy consumption. The data for renewable energy are composed from the Integrated National Energy Modeling System (INEMS) (INEMS, 2013). The annual data is used for all provinces. The details of calculations and sources used are available at http://inems1.bit.edu.cn/Home/Menu. The nonrenewable energy data is collected from China Statistical Yearbook using coal, natural gas and crude oil to calculate NRE values for each province. The unit for energy consumption is the kg of oil equivalent per capita. The annual data is used for all variables in this study for five provinces of China namely: Qinghai, Gansu, Xinjiang, Ningxia and Shaanxi for the period of 1995−2014. The natural log of all data is used to obtain the consistent results. Additionally, RE, NRE, GDP and TR represent the renewable energy consumption, nonrenewable energy consumption, GDP per capita and transportation, respectively. A separate model for each province is used to compare the variations for all provinces. Last few decades have witnessed dramatic increase of CO_2 emissions in China. The emissions level in China is more than the collective emissions of the USA and the European Union (Ye et al., 2017). As the largest developing country and a fastest growing economy, remarkable economic growth of China is no secret to the world, and immense energy is required to sustain this development (J. J. Jiang et al., 2019). Thus, this rapid growth has considered a dominant factor for environmental pollution. Likewise, developing nations resort to fossil fuels relatively more than renewable energy making nonrenewable energy an important variable for current study. It is a well-known fact that consumption of these nonrenewable energy sources are associated with increased environmental pollution (BP, 2018). Similarly, rapid growth and urbanization stimulate transportation demand and environmental pollution in China because this increased demand is associated with substantial use of fossil fuels. Road transportation generates significant CO_2 emissions resulting increased air pollution in China (Lu et al., 2020). Therefore, among other factors, these variables play very important role to understand energy environment nexus and used as control variables in current study.

3.2. Estimation procedure

3.2.1. Stationary check

The Zivot and Andrews (2002), and Kim and Perron (2009) tests are employed to test the unit root in all variables of on hand study. These methods are more appropriate than traditional tests to solve the issue of structural breaks. The common econometric form of these tests can be written as follows:

$$\Delta X_t = b + bx_{t-1} + ct + bDT_t + \sum_{j=I}^{k} d_j \Delta X_{t-j} + \mu_t \quad (1)$$

$$\Delta X_t = c + cx_{t-1} + ct + dDU_t + dDT_t + \sum_{j=I}^{k} d_j \Delta X_{t-j} + \mu_t \quad (2)$$

The mean shift and time break for each point is explained with the dummy of DU_t. Whereas, DT_t indicates series time breaks. The null hypothesis c = 0 denotes that the data has a unit root. On the other hand, the alternative hypothesis c < 0 states the data is free from unit root. These tests consider all possible break points and provider better results about stationary properties of time series data.

3.2.2. The NARDL approach

The present paper uses the NARDL model to capture the long and short run dynamics of renewable energy and environmental pollution association. This method is an asymmetric expansion of linear autoregressive distributed lag model (ARDL) (Pesaran et al., 2001). The NARDL framework allows co-integration and asymmetric non-linearity in a single equation and more suitable for smaller sample than other methods. This approach is suitable for 1 (0), 1 (1) or a combination of both order of integration. The NARDL mixes short-run change to long-run symmetry taking the long-run information into account due to the specific features (Shin et al., 2014). Furthermore, the conventional methods including the vector error correction model (VECM) or smooth transition model (STM) are not much effective to deal with convergence issue in case of proliferation of estimations. This approach is more suitable to counter this problem. Likewise, this approach is effective at any order of integration, and this order flexibility increase the importance of the NARDL over other approaches. On the same note, this method solves the multicollinearity concern with effective automatic lag selection and uses the best model (Shahbaz, 2018). Additionally, considering both positive and negative shocks, the NARDL provides better understanding of renewable energy and environment connection, which makes it the better choice over previous conventional methods. Considering that the NARDL is an advanced form of ARDL and the general form can be written as follows:

$$\Delta Y_t = \mu + \rho Y_{t-1} + \theta' x_{t-1} + \sum_{j=1}^{p-1} \alpha_j \Delta Y_{t-1} + \sum_{j=0}^{q-1} \pi_j \Delta x_{t-1} + \varepsilon_t \quad (3)$$

where Δ represents first difference operator, Y_t states dependent variable, μ is the intercept, x_t symbolizes a k _ 1 vector of regressor, ρ and θ are the long-run coefficients. Whereas α_j and π_j are short-run coefficients, p and q represent lags order of individual variables π_j and is white noise error term. The null hypothesis states that the variables are not associated and the alternative hypothesis supports a long run connection. The conclusion rule is established on matching the calculated F-statistic values with the critical values, which are derived from (Pesaran et al., 2001). If the calculated F-statistic values are larger than the upper bound values, I (1) then the long run connection proves true among variables. Conversely, if the estimated F-statistic values fall under the lower bound values, I (0), this indicates that the variables involved in the simulations share no long run association. Finally, if the calculated F-statistic values fall in between the upper and lower bound, it cannot in this case ascertain with certainty whether or not any long run connection exists. Nevertheless, key assumption of ARDL method proposes that independent variables have symmetric effect on dependent variable that can be misleading (Luqman et al., 2019). Following Shin et al. (2014), the NARDL model can be constructed upon the following asymmetric long-run equilibrium associations:

$$Y_t = \beta^+ X_t^+ + \beta^- X_t^- + \mu_t \quad (4)$$

where μ_t describes deviance of long term symmetry, β^+ and β^- signifies associations of irregular long term restrictions. The vector x_t can be disintegrated as follows:

$$X_t = X_0 + X_t^+ + X_t^- \quad (5)$$

The positive and negative change in X can be described as

follows:

$$X_t^+ = \sum_{j=1}^{t} \Delta X_j^+ = \sum_{j=1}^{t} \max(\Delta X_j, 0) \tag{6}$$

$$X_t^- = \sum_{j=1}^{t} \Delta X_j^- = \sum_{j=1}^{t} \min(\Delta X_j, 0) \tag{7}$$

where j and X_j indicate the asymmetric distributed and asymmetric distributive lags of X. The disproportionate error correction model can be attained with the combination of equation (3) and equation (4). The combined model can be specified as follows:

$$\Delta Y_t = \mu + \rho Y_{t-1} + \theta^+ X_{t-1}^+ + \theta^- X_{t-1}^- + \sum_{j=0}^{q-1} (\pi_j^+ \Delta X_{t-j}^+ + \pi_j^- \Delta X_{t-j}^-) + \varepsilon_t \tag{8}$$

The NARDL and ARDL follow the similar process in which the standardized ordinary least square (OLS) system is used to get error correction model from equation (8). After this, existence of unbalanced long term association is tested using the bound test. Since, F-statistics depends on the direction of assimilation of variables, the pragmatic bound test method, proposed by Pesaran et al. (2001) is also employed in the NARDL model. Similarly, the long and short term asymmetries are tested through the Wald test. Finally, asymmetric dynamic multiplier including all existing and former effect of positive and negative modification of independent variable on the dependent variables can be defined as follows:

$$m_h^+ = \sum_{j=0}^{h} \frac{\partial y_{t+j}}{\partial x_t^+}, \; m_h^- = \sum_{j=0}^{h} \frac{\partial y_{t+j}}{\partial x_t^-}, \; h = 1, \ldots, n \tag{9}$$

After the confirmation of unit root and order of integration, the on hand study proceeds to test the effect of renewable energy on ecological pollution with the NARDL co-integration approach. The general form of this approach using the main dependent and independent variable in p and q form can be formed as follows:

$$\begin{aligned} \Delta CO2_t = {} & \alpha_0 + \rho CO2_{t-1} + \theta_1^+ RE_{t-1}^+ + \theta_1^- RE_{t-1}^- + \theta_2^+ \\ & \times \sum_{j=1}^{2} \beta_j controls_{t-1}^+ + \theta_2^- \sum_{j=1}^{2} \beta_j controls_{t-1}^- + \sum_{i=1}^{p-1} \alpha_i \Delta CO2_{t-i} \\ & + \sum_{i=0}^{q} \pi_{1,i}^+ \Delta RE_{t-1}^+ + \sum_{i=0}^{q} \pi_{1,i}^- \Delta RE_{t-1}^- + \sum_{i=0}^{q} \pi_{2,i}^+ \Delta \sum_{j=1}^{2} \beta_j controls_{t-1}^+ \\ & + \sum_{i=0}^{q} \pi_{2,i}^- \sum_{j=1}^{2} \beta_j controls_{t-1}^- + \varepsilon_t \end{aligned} \tag{10}$$

where, subscript t denotes time and α_0 indicates the parameter to be estimated. The CO_2 and RE are the carbon emissions and renewable energy and represents the dependent and independent variable, respectively. The controls specify different control variables incorporated in the study to estimate the impact of renewable energy on environmental degradation. The RE, NRE, GDP and TR represent the renewable energy consumption, nonrenewable energy consumption, GDP per capita and transportation, respectively. These variables are used as control variables. Currently, fossil fuels are one of the main sources of energy, and consumption of these nonrenewable energy sources are associated with increased environmental pollution (BP, 2018). Likewise, the main source of energy in transportation sector is fossil fuels. This makes transportation sector an important contributor towards environmental pollution. Finally, remarkable economic growth of China is no secret to the world, and immense energy is required to sustain this development. Currently, China is the second main petroleum user and the second highest in terms of petroleum-related CO_2 emissions (IEA, 2017). Therefore, among other factors, these variables play very important role to understand energy environment nexus.

4. Empirical results and discussion

4.1. Unit root results

As the preliminary step, the study uses the unit root tests to confirm the stationary properties of all variables. The traditional unit tests may provide biased estimations due to weak explanatory features and overlook the significance of fundamental breaks in the data. This leads to the acceptance of inadequate null hypothesis and provides vague results regarding the unit root in a time series (Shahbaz, 2018). The Zivot and Andrews (2002) and Kim and Perron (2009) tests are employed to deal with the unit root among the variables. These tests provide better results regarding unknown single structural break in the data. The outcomes are stated in Table 1.

The outcomes of Gansu province designate that the calculated values are less that the critical value. This shows that all variables possess unit root issue at level. But, the variables become free from this problem at the 1st difference. Both tests indicate various breaks in the data at both levels. The estimations of Qinghai province show that maximum variables have unit root issue at level except the renewable energy. The values are significant at level that means this variable is stationary. The remaining variables become stationary at the 1st difference. The results of K–P test for Qinghai describe that transportation has no unit root at level. The rest of variables become stationary after taking the first difference. Moving towards the Shaanxi outcomes, the estimations follow the same trend as for Qinghai. The estimates of Z&A (Zivot and Andrews) test confirm the unit root for all variables at level except renewable energy and the remaining variables become unit root free at 1st difference. The results of K–P test indicate the unit root issue at level for all variables except transportation. At the 1st difference, the estimate of Shaanxi indicates no issue unit root. The outcomes of Z&A test in the case of Ningxia illustrate the unit root at level in all variables whereas; all variables become stationary after taking 1st difference. However, the results of K–P test confirm that variables are stationary after taking the 1st difference except renewable energy and transportation. In case of Xinjiang, both tests follow the similar pattern. The Z&A test results support the removal of unit root at 1st difference, whereas, the estimates of K–P indicate that GDP and renewable energy are stationary at level. Overall, all variables have a mix trend for all provinces and the variables are incorporated at level and 1st difference. None of variables are connected at second difference. The results confirm the preliminary requirement to apply the ARDL approach.

4.2. BDS and the bounds test for NARDL to co-integration results

To test the presence of non-linearity, the paper uses the BDS approach. The Broock et al. (2007) developed this method to test the expected residuals of a time series model converted into a model of autonomous and identically scattered errors. The null hypothesis states that the series is independently and identically distributed. The results are presented in Table 2. The estimated Z-stat indicates that all values are significant. This leads to the

Table-1
Unit root analysis.

Province	Variables	Z&A Level		1st difference		K.P Level		1st difference	
		T-statistics	Breaks	T-statistics	Breaks	T-statistics	Breaks	T-statistics	Breaks
Gansu	CO2	−4.12(1)	2010	−7.59(0)	2002	−2.76(4)	2010	−9.54(1)	2011
	GDP	−3.94(0)	2004	−6.61(0)	2000	−3.23(0)	2004	−6.22(0)	2009
	NRE	−3.12(0)	1998	−5.69(1)	2002	−2.21(0)	2002	−8.10(1)	2003
	RE	−3.69(0)	2001	−6.15(1)	2004	−0.83(0)	2004	−5.35(2)	2003
	TR	−4.06(0)	2008	−5.44(1)	2011	−2.25(0)	2008	−10.47(1)	2009
Qinghai	CO2	−3.99(0)	2000	−5.88(0)	2006	−2.32(4)	2006	−7.72(3)	2005
	GDP	−3.95(0)	2009	−5.49(1)	2010	−3.48(0)	2002	−9.64(2)	2001
	NRE	−3.85(0)	2000	−5.71(1)	2003	−1.54(0)	2002	−5.30(4)	2006
	RE	−6.19(2)*	2001	–	–	−0.52(4)	2007	−7.70(3)	2008
	TR	−2.40(0)	2008	−5.94(1)	2011	−6.41(4)*	2007	–	–
Shaanxi	CO2	−4.13(2)	2010	−5.88(1)	2001	−2.11(4)	2004	−10.85(3)	2003
	GDP	−3.37(0)	2004	−6.19(0)	1999	−2.86(1)	2002	8.80(2)	2011
	NRE	−4.02(0)	2001	−6.39(1)	2004	−1.58(0)	2002	−11.23(0)	2003
	RE	−5.16(0)*	2004	–	–	−1.33(3)	2002	−5.22(1)	2004
	TR	−3.27(0)	2008	−6.14(1)	2010	−7.21(4)*	2007	–	–
Ningxia	CO2	−3.75(1)	2002	−5.62(1)	2004	−1.74(0)	2002	−5.84(2)	2003
	GDP	−3.14(0)	2003	−5.62(1)	2004	−2.80(0)	2011	−9.83(1)	2012
	NRE	−3.49(0)	2004	−6.12(1)	2008	−1.76(0)	2002	−7.95(1)	2011
	RE	−1.90(0)	2000	−11.90(1)	2002	−8.38(4)*	2011	–	–
	TR	−2.59(0)	2007	−9.78(0)	2010	−5.76(4)*	2005	–	–
Xinjiang	CO2	−2.05(0)	1999	−7.52(0)	2003	−1.27(3)	2008	−6.37(0)	2003
	GDP	−3.69(0)	2009	−5.65(0)	2010	−5.98(0)*	2009	–	–
	NRE	−1.22(2)	2010	−5.97(1)	2011	−1.02(3)	2010	−12.57(1)	2009
	RE	−3.57(2)	2009	−9.67(0)	2011	−6.16(0)*	2006	–	–
	TR	−2.19(0)	1998	−8.20(0)	2004	−2.15(0)	2003	−7.78(0)	2013

Notes.
1. "*" specifies the variables become stationary at levels.

acceptance of alternative hypothesis and suggests that data is a non-normal distribution. This confirms the non-linearity between the variables and the implication of NARDL to examine the association between renewable energy and environmental degradation.

The bound test main assumption suggests that coefficients of selected items are equivalent to zero. The results of Table 3 indicate that the calculated F-Statistics are substantial and approve the presence of a long term relationship among variables. Whereas, the F-Statistics of five provinces surpass the upper bounds stated in (Pesaran et al., 2001). The estimations suggest s long term connection among the variables of each province.

The confirmation of asymmetric co-integration leads to the short and long run asymmetric relationship for on hand variables. The appropriate NARDL model is selected through general to specific method. The existence of irrelevant coefficients leads to the inaccuracy of estimates which can affect the dynamic multiplier. Therefore, the insignificant variables have been dropped. Table 4 reports the outcomes. The long and short run Wald test statistics are significant and reject the null hypothesis $\theta^{+} = \theta^{+} = 0$. This verifies the suitability of asymmetric model and suggests that positive and negative shocks might differently associate with dependent variables for each province. The Wald test statistics of all variables for each province varies but significant in long run. Similarly, the short run Wald test outcomes are tested using the null against alternative hypothesis: $\sum_{i=0}^{q} \pi_{k,i}^{+} = \sum_{i=0}^{q} \pi_{k,i}^{-}$ or all explanatory variables. All short run test statistics reject the null and confirm a significant effect of positive and adverse variations in descriptive variables. Overall, the Wald test statistics also confirm the suitability of the NARDL model and indicates that overlooking asymmetries in dynamic estimations can lead to inaccurate estimations.

4.3. The NARDL results

After the initial analyses, this discussion follows the short and long run coefficients of the NARDL. Table 5 describes the short run results for the five provinces. The positive shocks exist in renewable energy has a harmful effect on the CO_2 emissions of five provinces. This specifies that the renewable energy use decreases the environmental pollution in the Northwestern provinces. The impact of renewable energy consumption varies in these five provinces. The effect is significant in Gansu, Qinghai and Xinjiang than in Ningxia and Shaanxi. Similarly, the negative shock in the renewable energy escalates CO_2 emissions. This leads to the conclusion that an increased consumption of renewable energy improves environmental quality and the reduction in renewable energy use results in augmentation of CO_2 which degrades the environment. These results are similar with the outcomes of Wang et al. (2019) suggesting that the contribution of non-fossil fuels to CO_2 emission reduction in 30 Chinese provinces is significant. However, the impact is more obvious for the post-reform period supporting that the renewable energy sources improve the environment in different Chinese regions. Positive shocks in the non-renewable energy use have a substantial positive effect on the CO_2 emissions in all provinces. This illustrates the increased consumption of traditional energy leads to environmental pollution.

On the other hand, negative shocks in the energy consumption decline the CO_2 emissions. In most cases, the coefficients are not strongly significant indicating that the pollution control takes time and continuous efforts to introduce better alternatives to the traditional energy sources. These findings are consistent with Chen et al. (2019) concluding that the non-renewable energy adverse impact on environment was most significant in central, Northwestern and eastern region, respectively. Whereas, renewable energy reduced the CO_2 emissions in Northwestern and eastern regions and effect was insignificant in central region of China. Similarly, the increased economic development is associated with the high CO_2 emissions due to massive energy use. The positive coefficients of GDP indicate a significant adverse effect on the ecological quality of all provinces in the short run. However, adverse shocks decline the level of CO_2 emissions. As, Han et al. (2018) also suggested that economic development is significantly

Table-2
BDS test for non-linearity.

Gansu											
		lnCO2		lnRE		lnGDP		lnNRE		lnTR	
Gansu	Dimensions	BDS	Z-stat	BDS	Z-stat	BDS	Z-stat	BDS	Z-stat	BDS	Z-stat
	2	0.16	16.08	0.17	17.38	0.60	8.58	0.13	12.81	0.16	10.04
	3	0.26	15.84	0.27	16.8	0.36	12.10	0.20	11.92	0.25	9.50
	4	0.32	15.69	0.32	16.14	0.29	10.39	0.22	10.44	0.26	8.02
	5	0.33	15.28	0.34	15.92	0.31	12.38	0.17	7.59	0.23	6.42
	6	0.30	14.07	0.29	13.95	0.30	14.31	0.11	5.02	0.12	3.37
Xinjiang											
Xinjiang	Dimensions	BDS	Z-stat	BDS	Z-stat	BDS	Z-stat	BDS	Z-stat	BDS	Z-stat
	2	0.15	11.84	0.10	5.07	0.44	6.05	0.15	16.24	0.14	10.87
	3	0.21	10.23	0.11	3.11	0.41	8.15	0.24	15.38	0.19	8.61
	4	0.21	8.14	0.48	5.20	0.23	7.52	0.19	12.43	0.17	6.23
	5	0.15	5.44	0.58	6.33	0.17	5.16	0.34	9.56	0.77	5.58
	6	0.12	7.45	0.24	5.57	0.21	9.14	0.29	11.58	0.58	8.93
Shaanxi											
Shaanxi	Dimensions	BDS	Z-stat	BDS	Z-stat	BDS	Z-stat	BDS	Z-stat	BDS	Z-stat
	2	0.14	13.51	0.11	7.14	0.19	8.99	0.18	18.77	0.15	10.74
	3	0.21	12.24	0.21	9.12	0.14	8.47	0.29	18.29	0.26	11.35
	4	0.23	10.72	0.16	11.82	0.19	9.63	0.35	17.82	0.28	9.81
	5	0.19	8.40	0.21	6.14	0.21	8.92	0.38	18.07	0.25	8.01
	6	0.43	5.10	0.17	8.81	0.18	6.10	0.37	17.71	0.14	4.53
Qinghai											
Qinghai	Dimensions	BDS	Z-stat	BDS	Z-stat	BDS	Z-stat	BDS	Z-stat	BDS	Z-stat
	2	0.13	12.27	0.15	14.43	0.19	5.69	0.17	17.50	0.14	8.37
	3	0.20	11.19	0.24	13.99	0.17	7.50	0.27	16.80	0.22	7.59
	4	0.21	9.41	0.27	12.92	0.23	11.33	0.32	15.96	0.22	6.23
	5	0.17	7.16	0.26	11.15	0.24	9.14	0.31	14.66	0.18	10.55
	6	0.15	6.22	0.15	6.64	0.11	14.94	0.24	11.36	0.12	7.75
Ningxia											
Ningxia	Dimensions	BDS	Z-stat	BDS	Z-stat	BDS	Z-stat	BDS	Z-stat	BDS	Z-stat
	2	0.16	15.68	0.13	12.18	0.16	11.60	0.17	18.28	0.15	9.16
	3	0.26	14.67	0.19	11.19	0.17	14.39	0.28	17.74	0.23	8.58
	4	0.30	13.76	0.23	10.65	0.21	16.96	0.35	17.60	0.24	7.43
	5	0.30	12.78	0.27	11.84	0.18	15.34	0.37	17.59	0.21	5.94
	6	0.28	11.89	0.31	13.47	0.19	12.40	0.40	18.70	0.11	9.04

Table 3
Bounds test results.

Provinces	F-statistic	Critical values		Results
		I(0) bound	I(1) bound	
Gansu	7.67	2.26	3.35	Co-integrated
Ningxia	9.55	2.62	3.79	Co-integrated
Qinghai	9.73	3.41	4.68	Co-integrated
Shaanxi	8.10			Co-integrated
Xinjiang	15.98			Co-integrated

Note: Critical values are given for 10%, 5% and 1%, respectively. CO_2 is the dependent variable.

associated with CO_2 emissions in less developed Northwestern region of China.

Likewise, the positive shocks in transportation enhance the pollution and reduction is associated with less CO_2 emissions. This leads to the conclusion that increased energy consumption in transportation sector adversely affect the environment. The lagged values of renewable energy positive shock reduces the CO_2 emissions in all provinces and majority of the coefficients are significant. Whereas, the negative shocks of the lagged coefficients show an adverse impact of less renewable energy use on environment in Gansu and Qinghai in the short run. The positive lagged coefficients

Table 4
The long and short run asymmetries under Wald test.

Variables	Gansu		Ningxia		Qinghai		Shaanxi		Xinjiang	
ln RE^L	5.46**	(0.018)	12.37***	(0.000)	25.61***	(0.000)	15.27***	(0.000)	10.67***	(0.000)
ln RE^S	14.92***	(0.000)	8.20***	(0.000)	15.78***	(0.000)	11.43***	(0.000)	7.63***	(0.000)
ln NRE^L	10.84***	(0.000)	11.44***	(0.000)	12.34***	(0.000)	14.16***	(0.000)	5.89**	(0.024)
ln NRE^S	9.03***	(0.000)	14.80***	(0.000)	11.35***	(0.000)	19.29***	(0.000)	5.38**	(0.009)
ln GDP^L	10.64***	(0.000)	13.02***	(0.000)	5.16**	(0.006)	5.24**	(0.007)	8.37***	(0.000)
ln GDP^S	8.97***	(0.000)	15.63***	(0.000)	6.46**	(0.009)	7.97***	(0.000)	12.47***	(0.000)
ln TR^L	7.61***	(0.000)	9.32***	(0.000)	7.88***	(0.000)	9.14***	(0.000)	6.27***	(0.000)
ln TR^S	8.32***	(0.000)	16.47***	(0.000)	9.25***	(0.000)	11.71***	(0.000)	16.03***	(0.000)

The "**, ***" signify the 5% and 1% level of significance respectively. P values are given in the parenthesis. The L and S indicate the long and short run symmetries.

Table 5
Short-run results.

Variables	Gansu		Ningxia		Qinghai		Shaanxi		Xinjiang	
Const.	4.02**	(5.11)	2.27**	(2.41)	4.95**	(2.56)	3.36**	(4.42)	0.17**	(4.77)
$\ln CO_{2t-1}$	0.20**	(2.51)	−0.68**	(-2.56)	−0.54**	(-4.38)	−0.36**	(-2.15)	−0.39**	(-2.14)
$\ln RE^{+}$	−0.29**	(-5.78)	−0.26*	(-0.38)	−0.34**	(-4.68)	−0.99*	(-1.34)	−0.18**	(-3.16)
$\ln RE^{-}$	0.50*	(0.69)	0.28*	(1.72)	0.76*	(0.81)	0.84**	(7.88)	0.11*	(1.57)
$\ln NRE^{+}$	0.80**	(5.75)	1.36**	(4.17)	0.44**	(2.30)	0.87**	(5.80)	0.53**	(3.18)
$\ln NRE^{-}$	−0.82*	(-1.49)	−1.14*	(-0.88)	−0.96**	(-3.12)	−0.53*	(-1.52)	−0.19*	(-1.59)
$\ln GDP^{+}$	0.16**	(3.71)	0.81**	(3.73)	−0.93*	(-1.56)	0.47**	(4.52)	0.60**	(3.41)
$\ln GDP^{-}$	−0.08**	(-2.65)	−0.51*	(-1.52)	−0.26*	(-1.06)	−0.16*	(-0.94)	−0.44*	(-0.94)
$\ln TR^{+}$	0.07*	(1.12)	0.69*	(1.31)	0.27**	(2.21)	0.29*	(1.24)	0.42**	(2.99)
$\ln TR^{-}$	−0.04*	(-0.79)	−0.95*	(-1.76)	−0.19*	(-1.21)	−0.26*	(-1.16)	−0.79*	(-1.55)
$\Delta \ln CO_{2t-1}$	0.14**	(9.14)	0.74**	(2.82)	0.35**	(4.68)	0.37**	(3.16)	−0.87**	(-3.77)
$\Delta \ln RE^{+}$	−0.41**	(-2.95)	−0.34*	(-1.25)	–	–	−0.76**	(-5.09)	−0.90**	(-4.19)
$\Delta \ln RE^{-}$	0.96*	(1.02)	–	–	0.82*	(1.81)	–	–	–	–
$\Delta \ln NRE^{+}$	–	–	1.32**	(3.47)	0.39**	(2.72)	–	–	0.87**	(3.58)
$\Delta \ln NRE^{-}$	−0.90**	(-2.70)	−1.84*	(-0.38)	–	–	−0.26**	(-3.82)	–	–
$\Delta \ln GDP^{+}$	0.22**	(3.78)	0.78*	(1.07)	–	–	–	–	0.15**	(4.02)
$\Delta \ln GDP^{-}$	–	–	−0.89*	(-1.84)	−0.62*	(-1.46)	−0.40**	(-2.90)	–	–
$\Delta \ln TR^{+}$	0.09*	(1.44)	0.76*	(0.61)	0.51*	(1.81)	0.35**	(2.16)	–	–
$\Delta \ln TR^{-}$	−0.06*	(-1.02)	−0.59*	(-0.55)	−0.57*	(-1.89)	–	–	−0.18**	(-2.30)

The superscript "+" and "-" outlines positive and adverse fractional calculation in the short run. The 5% and 10% level of significance is described with "**, *" respectively.

of non-renewable energy increase the environmental pollution in Ningxia, Qinghai and Xinjiang. The negative energy shocks are associated with reduced pollution in Gansu, Ningxia and Shaanxi. The positive shocks in the GDP lagged coefficients increase the CO_2 emissions in Gansu, Ningxia and Xinjiang. Whereas, the negative shocks reduces emissions level in Ningxia, Qinghai and Shaanxi at different significance level. Finally, in case of transportation, the positive lagged coefficient of Gansu, Qinghai, Ningxia and Shaanxi have an adverse impact on environment. However, the negative shocks indicate a decline in CO_2 emissions for Gansu, Qinghai, Ningxia and Xinjiang at various levels of significance in the short run. This significant link of renewable energy towards sustainable development describes accelerated efforts of Chinese government to reduce pollution using renewable energy. Investment in clean energy is crucial for economic and environmental development. China holds one third of the total global renewable energy investment and thirteenth development plan suggests 39% increase in renewable energy. This additional investment is the practical example of Chinese government efforts for CO_2 emission reduction (Yang et al., 2019). China has surpassed the USA in terms of CO_2 emissions due to remarkable economic development, and government is committed to achieve significant reduction in CO_2 emissions. For this, China pledged to reduce CO_2 emissions up to 65% by 2030 in the joint climate control meeting with the USA. Subsequently, China worked on social transformation to achieve this goal through environmental friendly development. The central government emphasized on carbon reduction in recent development plans, and set various targets for all regions. The level of emissions reduction target is different for all regions depending on the economic development of a particular province. The developed ones are assigned relatively higher targets to support the sustainable development campaign, and reduced CO_2 emissions by 18% from 2016 to 2020 (Wen and Wang, 2020). However, a higher rate of risk is associated with this campaign as investments in cleaner production are attributed towards long run return. Thus, government financing and commitment has been leading towards positive outcomes in terms of less environmental pollution than previous decade with renewable energy use in various provinces. It can be concluded that significant link between renewable energy and pollution control is the outcome of Chinese government efforts towards sustainable development. The results of long run NARDL positive and negative dynamics are stated in Table 6.

The positive shocks confirm a harmful effect of renewable energy use on the environment in the long run for all provinces. However, this effect is more significant in Gansu, Qinghai and Xinjiang. The negative shocks increase the level of CO_2 emissions and this effect is more significant Ningxia and Shaanxi. In the long run, the use of nonrenewable energy sources augments the CO_2 emissions as the positive shocks indicate a significant positive impact of nonrenewable energy on environment. Furthermore, the reduction in energy use causes a significant decline in CO_2 emissions. Similarly, increased economic activities augment and reduction in these activities reduces the CO_2 emissions in the long run, respectively. Finally, the positive shock of transportation is associated with environmental degradation and the negative shock reduces the CO_2 emissions in the long run. The significance level of negative shock varies for each province.

The significant positive impact of renewable energy on environmental quality in three provinces indicates the abundance and utilization of renewable sources in these provinces for improved environment. For instance, Xinjiang has tremendous potential for wind and solar resources to decrease traditional energy sources use for rapid development. The statistics of Xinjiang power generation department describes that Xinjiang experienced 14.31% growth of renewable energy than previous year. The total capacity reaching 18.3 billion kWh (Xu et al., 2017). Likewise, the source province to three Chinese rivers, Qinghai province generates clean energy with its plentiful water resources. The provincial government is committed to generate ample amount of clean energy to reduce environmental pollution. This capacity development is expected to replace the burning of 50 million tons of coal by the end of this decade.

This shift towards renewable energy use is not only useful for Qinghai itself but also for the neighboring provinces (Liu et al., 2019). Similarly, Gansu province has also been developing its renewable energy capacity for rapid development of Silk Road projects. This province has one of the world's largest wind farms. This wind power generation capacity makes Gansu one of the important provinces in terms of renewable energy development. Besides, this province holds various renewable energy sources due to its high altitude (Yunna and Ruhang, 2013). Therefore, clean energy generation and progressive use of available sources help reducing environmental pollution in these provinces. Conversely, Shaanxi and Ningxia are still lagging behind than these three

Table 6
The long run estimations.

Variables	Gansu		Ningxia		Qinghai		Shaanxi		Xinjiang	
ln RE^+	−0.29**	(-3.85)	−0.30*	(-0.66)	−0.64**	(-4.63)	−0.23*	(-1.20)	−0.41**	(-9.62)
ln RE^-	0.61*	(0.88)	0.21**	(2.17)	1.95*	(0.98)	0.85**	(10.68)	0.75*	(1.53)
ln NRE^+	0.59**	(11.16)	1.01**	(15.58)	0.53**	(2.60)	−0.48**	(-9.67)	0.76**	(2.38)
ln NRE^-	−0.18**	(-2.45)	−1.41**	(-4.39)	−0.47**	(-2.04)	−0.76**	(-2.45)	−0.48**	(-5.72)
ln GDP^+	0.47**	(4.93)	0.53**	(3.09)	1.59**	(2.35)	0.20**	(4.34)	0.11**	(2.33)
ln GDP^-	−0.11**	(-2.71)	−0.25**	(-3.25)	−0.64**	(-2.14)	−0.62**	(-4.67)	−0.80**	(-3.19)
ln TR^+	0.02**	(3.41)	0.83**	(5.62)	0.72**	(3.37)	0.84**	(2.23)	0.69**	(4.88)
ln TR^-	−0.03**	(-2.29)	−0.74*	(-1.56)	−0.83**	(-4.75)	−0.75**	(-3.46)	−0.31*	(-1.52)

The superscript "+" and "-" outlines positive and adverse fractional calculation in the short run. The 5% and 10% level of significance is described with "**, *" respectively.

provinces in terms of renewable energy use, and the impact of clean energy on reducing pollution is also not significant. The proportion of fossil fuel use is still high in these two provinces. The use of renewable energy is particularly low in Shaanxi than other provinces (Yu et al., 2019). Thus, local governments of both provinces should accelerate their efforts to promote renewable energy utilization.

The long run results of the study are similar with the outcomes of Chen et al. (2019) supporting a long run association among CO_2 emissions, GDP, renewable, non-renewable energy production and foreign trade for China. Likewise, Dong et al. (2018) also suggested that renewable and nuclear energy significantly in mitigate CO_2 emissions, whereas fossil fuels consumption promotes CO_2 emissions. Furthermore, the impact of renewable energy is significant than the nuclear energy to mitigate the CO_2 emissions in the long run. Interestingly, there are few variations between the long and short run connection of these variables. More specifically, the impact of negative shocks varies significantly among all variables for all provinces. Generally, the negative shocks are not significant in short run, and this link and impact is significant for long run. The economic rationales for these variations are based on the fact that policies and restrictions for cleaner production need time for implementation, and positive outcomes normally can be observed after a reasonable time period. Similarly, limitations on fossil fuels use in transportation sector takes time and huge investment is required to implement these policies on a large scale. Therefore, the significant positive can normally be expected after a certain time period. Therefore, the present findings also certify that sustainable development can be achieved through commitment, investment in clean energy, and impact can be observed more clearly in the long run.

Overall, this study explored the symmetric and asymmetric aspect of the association concerning renewable energy and environmental pollution in the short run and long run for these provinces. The findings not only indicate the benefit of renewable energy use but also work as whistleblower and explain the consequences of decreasing the proportion of clean energy in various sectors of five underdeveloped Chinese provinces. This implies that this link moves both ways. For instance, it is not just the increased use of renewable energy which reduces environmental pollution but also the commitment and policies of provincial government. Furthermore, these findings clearly show that negligence or a cut down in cleaner energy and production leads to carbon augmentation in long run. Thus, these provinces need to make best use of available resources and maintain the share of clean energy in all sectors. Nonetheless, the continuous support of central government in form of renewable energy investment is needed to accomplish the goal to carbon mitigation through renewable energy in these provinces.

4.4. Asymmetric dynamic multipliers

The dynamic multiplier analyses of are employed to determine the impact of independent variables on the CO_2 emissions of five provinces. The dynamic multiplier has been estimated using the best fitted NARDL model. The positive and adverse variations of renewable energy, GDP, nonrenewable energy consumption and transport have been observed on CO_2 emissions. The asymmetry curve (green line) demonstrates the difference between dynamic multipliers associated with the stated shocks of all explanatory variables. The dotted small purple and brown lines represent the lower and upper bands at a 95% confidence interval. Fig. 5(a–d) represents the result for Gansu province. The dynamic multiplier indicates a significant effect of renewable energy on CO_2 emissions in short and long run. Similarly, the positive and adverse shocks in GDP, energy use also have significant impact on environment.

The dynamic multipliers of Ningxia are reported in Fig. 6. The estimations show that the connection of renewable energy and CO_2 emissions is not strongly significant in the both short and long run. The impact of economic development, energy use and transportation differ within the time length. The effect of energy use is positive indicating that the nonrenewable energy resources are associated with increased CO_2 emissions. Similarly, the economic development also adds to the ecological contamination in the short and long run. The transportation sector also consumes immense amount of fossil fuels which leads to the higher CO_2 emissions. However, reduction in the consumption of traditional energy and the low consumption of energy in development and transport sector reduce the level of environmental pollution in Ningxia in short and long run.

The results of Qinghai province are presented in Fig. 7. The positive and negative shocks have a significant influence on environmental pollution. The nonrenewable energy use adversely affects the environment and there are different time variations in the shocks. Furthermore, both economic growth and the transport increase the energy consumption and lead to the CO_2 augmentations in Qinghai in short and in long run.

Fig. 8 illustrates the dynamic multipliers of Shaanxi province. The impacts of renewable energy on CO_2 emissions relatively insignificant as the variations are not substantial. By and large, the association among CO_2 and rest of the variables is significant. The positive and negative shocks have significant variations with passage of time and increased energy consumption for economic and transportation development is linked with negative impact on the environment in Shaanxi province.

The dynamic multipliers of Xinjiang are presented in Fig. 9. The positive and negative impact renewable energy shocks is significant on the environmental pollution. The positive shocks from transportation significantly increase the CO_2 emissions. However, the variations in GDP and energy consumption are relatively small but the impact is obvious in the long and short run in Xinjiang. Overall, dynamic multipliers of all provinces indicate significant association among CO_2 emissions and all other variables. By and large renewable energy reduces the ecological degradation in short and in long

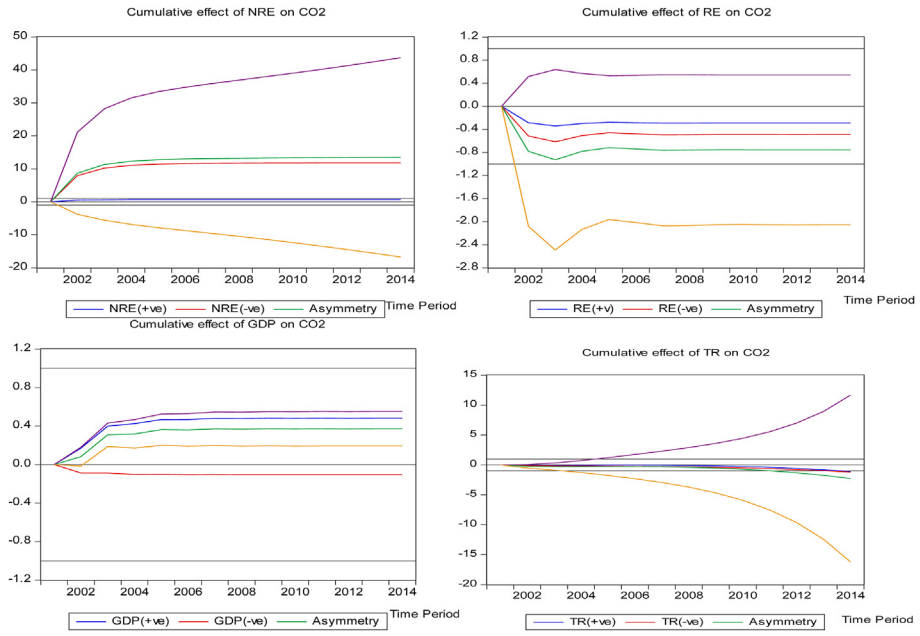

Fig. 5. In the dynamic multipliers subplots, blue line indicates positive variations, red is for negative changes, and green line describes asymmetries. The purple and brown lines shows upper and lower band (Gansu). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

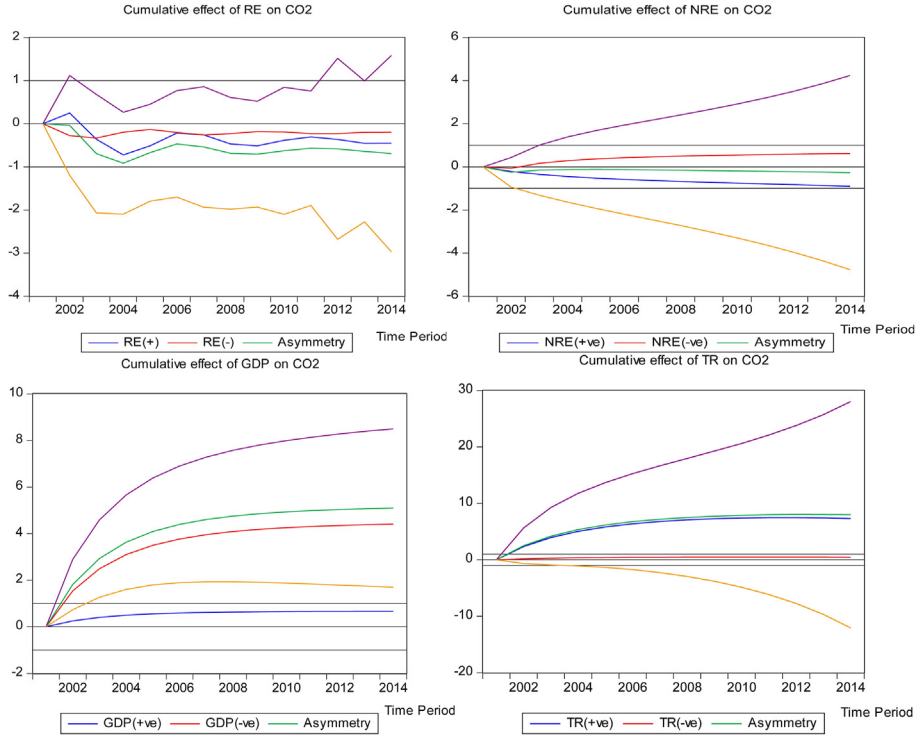

Fig. 6. In the dynamic multipliers subplots, blue line indicates positive variations, red is for negative changes, and green line describes asymmetries. The purple and brown lines shows upper and lower band (Ningxia). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

run. However, the positive shocks in nonrenewable energy, economic development and the transportation increase the CO_2 emission and degrade the environmental quality of these provinces.

The diagnostic tests results offered in Table 7. The F-statistic values and the corresponding probabilities for five provinces are not significant. This leads to the acceptance of null indicating heteroscedasticity and serial correlation do not exist in all models of this study.

The reliability of estimation has been confirmed through the CUSUM and CUSUM squares. The outcomes of five provinces are stated in Fig. 10. All CUSUM and CUSUM squares fall within critical bounds at 5% level of significance. This displays that observed outcomes are consistent and stable for each province.

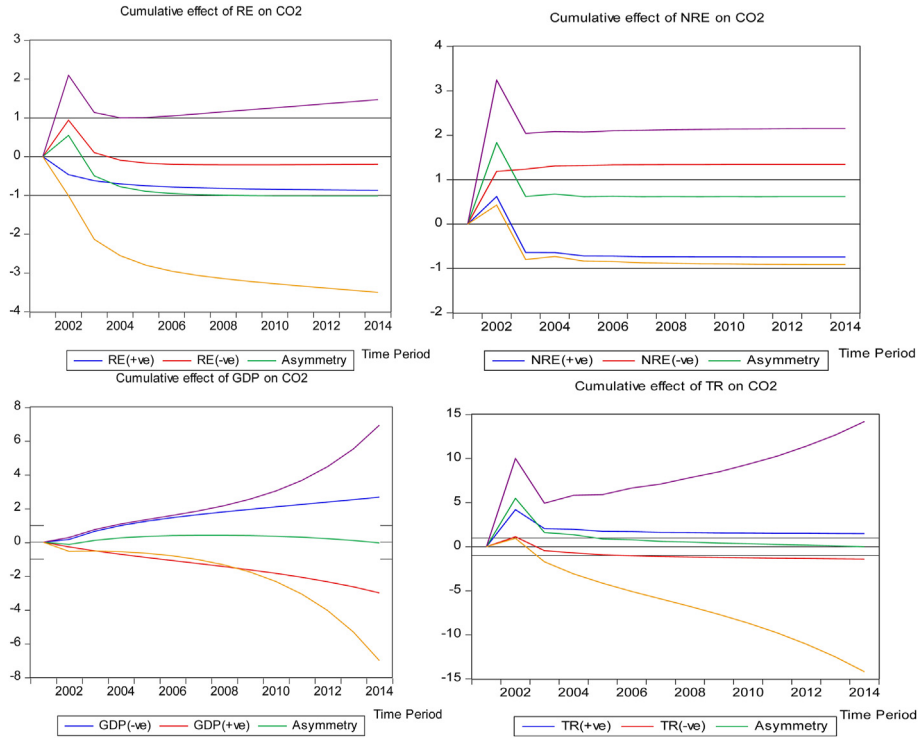

Fig. 7. In the dynamic multipliers subplots, blue line indicates positive variations, red is for negative changes, and green line describes asymmetries. The purple and brown lines shows upper and lower band (Qinghai). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

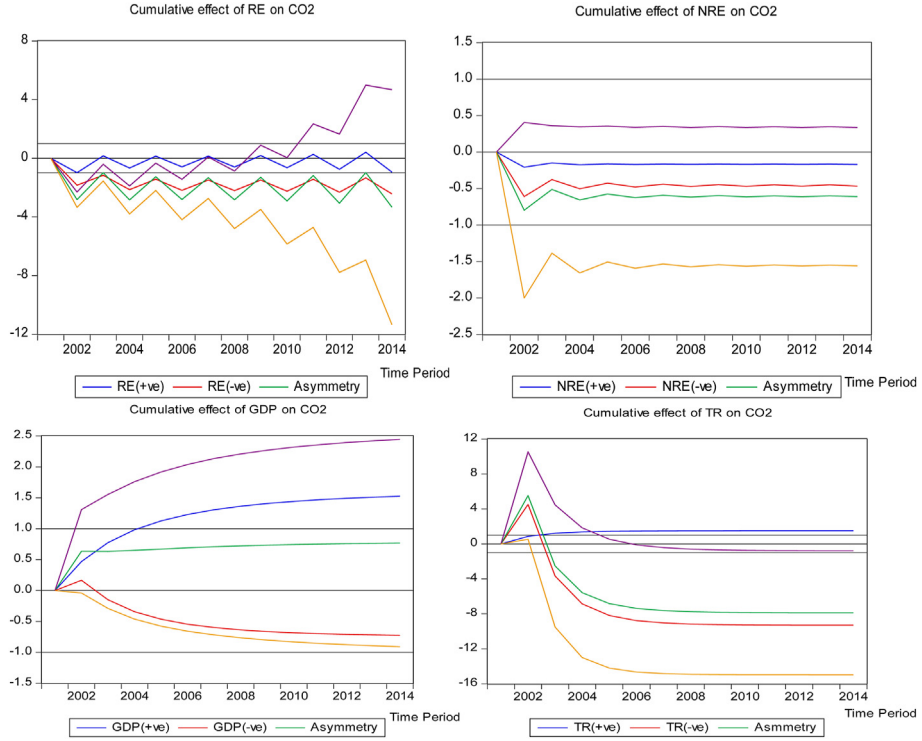

Fig. 8. In the dynamic multipliers subplots, blue line indicates positive variations, red is for negative changes, and green line describes asymmetries. The purple and brown lines shows upper and lower band (Shaanxi). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

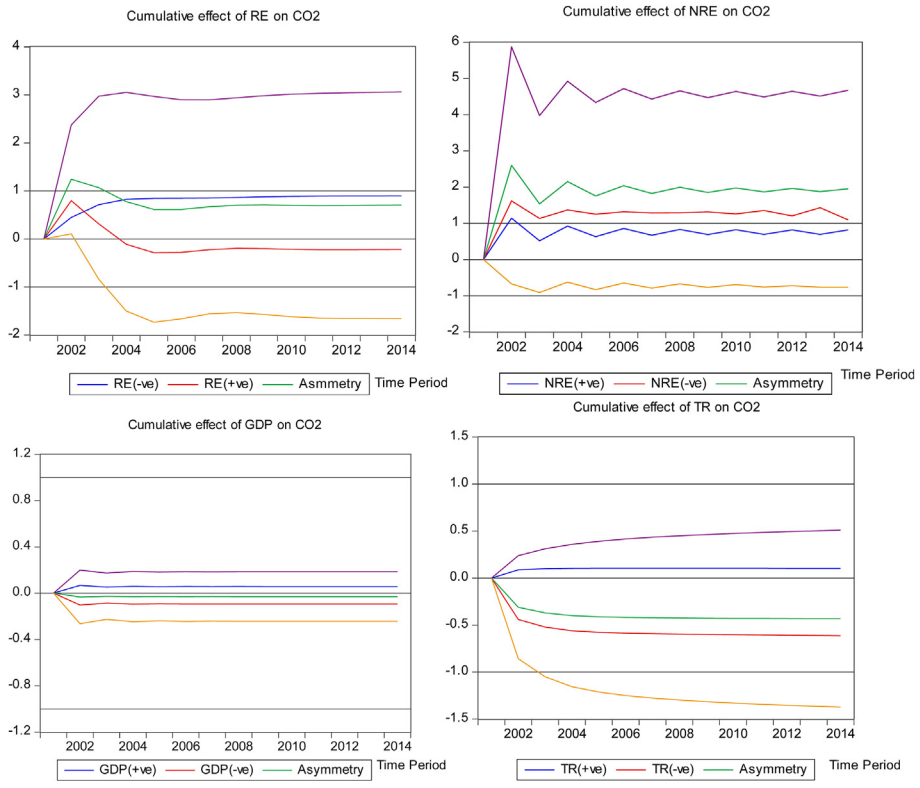

Fig. 9. In the dynamic multipliers subplots, blue line indicates positive variations, red is for negative changes, and green line describes asymmetries. The purple and brown lines show upper and lower band (Xinjiang). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 7
Diagnostics statistics results.

Provinces	x^2*SERIAL*		x^2*WHITE*		x^2*RAMSEY*	
	F. statics	Probability	F. statics	Probability	F. statics	Probability
Gansu	1.28	0.33	1.22	0.38	0.84	0.38
Ningxia	0.95	0.43	1.28	0.35	1.01	0.34
Qinghai	1.55	0.27	1.95	0.16	0.72	0.46
Shaanxi	0.93	0.44	1.19	0.40	0.34	0.73
Xinjiang	1.92	0.25	0.14	0.99	0.46	0.66
DW	2.10	2.45	1.98	1.95	2.27	
R^2	0.89	0.94	0.84	0.79	0.94	
Adj. R^2	0.91	0.95	0.87	0.84	0.96	

x^2*SERIAL*, and x^2*WHITE* represent serial correlation, normality, and Heteroscedasticity tests. DW is the Durbin-Watson stat.

5. Conclusion and policy implications

The recent literature focused on the environmental impacts of energy consumption; to promote sustainable development, decrease in CO_2 emissions with the help of renewable energy sources has been a main area of concern for academicians, specialists and policy makers all over the world. Empirical results are diverse on this subject due to data variations from various countries, sample size and econometric approaches. A significant gap still exists in the current literature to offer inclusive policy implications and to achieve sustainable financial expansion with suitable energy policy in various regions. Therefore, this study inspects the impact of renewable energy on environmental degradation from 1995 to 2014. We have added nonrenewable energy, GDP and transportation as the additional variables for five Northwestern provinces of China.

The on hand study used the Z&A and KP tests for unit root estimations; these tests provide better results regarding unknown breaks in the data. The unit root outcomes confirmed that variables are connected at I(0) and I(1). After confirming the non-linearity between the variables this paper applied the NARDL to examine the association between renewable energy and environmental degradation. The empirical estimations indicate the existence of symmetric and irregular co-integration among variables. The short run and long run coefficients of the NARDL specify that renewable energy positive shock has an adverse effect on the CO_2 emissions of the aforementioned provinces, which specifies that the renewable energy use reduces environmental pollution in the Northwestern Chinese provinces. The effect of renewable energy consumption varies in these five provinces; the effect is significant in Gansu, Qinghai and Xinjiang than in Ningxia and Shaanxi. However, the reduction in renewable energy use leads towards higher level of CO_2 emissions and this outcome is more substantial in Ningxia and Shaanxi in the long run.

Considering the results of additional variables, our estimations indicate that the positive shock of nonrenewable energy adds to the

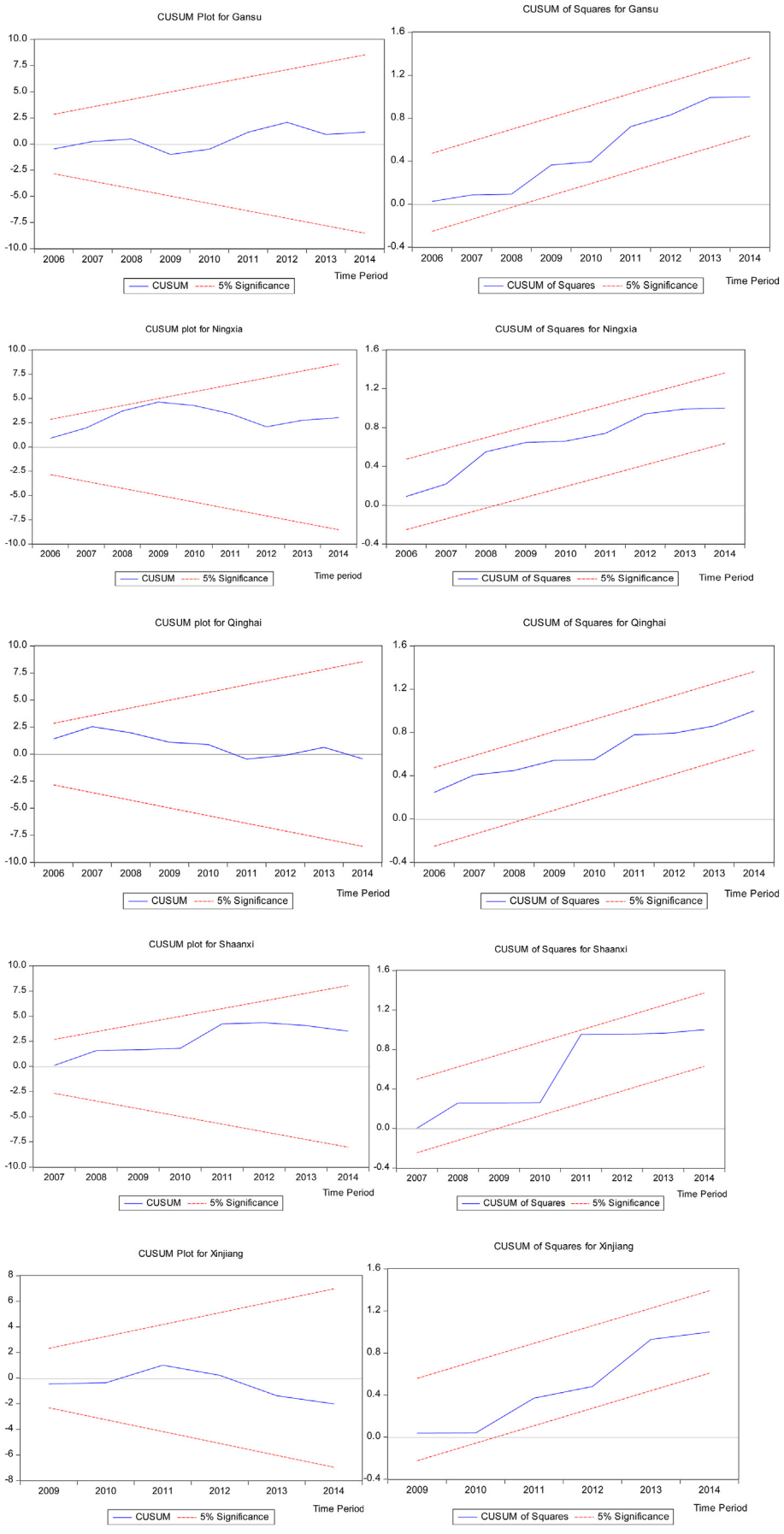

Fig. 10. Stability diagnostics.

environmental pollution in both short run and long run. Whereas, the adverse shock or less energy use mitigate the CO_2 emissions. This effect is more substantial in the long run for all provinces. Similarly, an increased economic development is linked with higher CO_2 emissions in the short run and long run. Whereas, the negative shock reduces the CO_2 emissions but the impact is substantial in the long run for majority of provinces. Finally, positive shocks in transportation increase CO_2 emissions in the long run. The adverse shock results in lower environmental pollution but this association is not strong in the short run and long run for all provinces except Xinjiang.

Overall, this study concludes that the energy consumption, to support the economic and infrastructural development of the less developed Northwestern Chinese provinces, is associated with environmental pollution in these provinces. However, the use of renewable energy helps to decrease CO_2 emissions in all provinces and this impact varies for each province in the short run and long run. Therefore, the use of alternative energy sources can be helpful in reducing environmental pollution and promoting sustainable development in these provinces of China.

The results of on hand study have significant policy insights. Firstly, renewable energy has been emerging as an ecofriendly source of economic development in the Northwestern region and the use of renewable energy can improve the arid and fragile climate of Northwestern provinces of China. However, more focus is needed in terms of R&D development to reduce the cost of renewable energy projects especially in Gansu, Qinghai and Xinjiang. Furthermore, technology intensive initiatives are required to improve the renewable energy performance in all provinces. Secondly, government of Shaanxi and Ningxia should focus to increase the installed capacity of renewable energy. Both provinces lagged behind in terms of renewable energy use and performance for reducing CO_2 emissions. Thirdly, local governments should not only increase the proportion of clean energy but also reduce primary energy consumption in transport and economic sector. Likewise, these provinces should control fossil fuel intensive economic activities and also maintain the current level of renewable energy for long run CO_2 emissions mitigation. Considering the poor economic conditions of China's Northwestern region, the economic and infrastructural problems can hinder the renewable development policies in these provinces. Therefore, central government should allocate additional investments in renewable energy infrastructure to promote energy efficiency. Furthermore, provision of subsidies from central government to promote the use of renewable energy can also help to maintain a balanced economic and environmental improvement of these less developed provinces. Finally, strict check and balance from authorities to monitor the progress of renewable energy targets especially in low performing provinces can be helpful to achieve the ultimate target of sustainable development in these provinces.

Finally, taking the importance of renewable energy sources into account, the future studies can be carried on the nexus of green energy and current environmental issues in the Belt and Road nations. Similarly, comparative studies of the less developed and advanced regions can also enrich the current literature on energy and environmental issues. The findings of such studies can be helpful in introducing suitable energy policies for sustainable development in the long run.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Fayyaz Ahmad: Formal analysis, Writing - review & editing, Methodology, Writing - original draft, Project administration. **Muhammad Umar Draz:** Investigation, Project administration, Writing - original draft, Writing - review & editing. **Ilhan Ozturk:** Writing - review & editing. **Lijuan Su:** Data curation, Writing - review & editing. **Abdul Rauf:** Writing - review & editing.

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