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RESEARCH ARTICLE

Policy inference from technological innovation, renewable energy, and financial development for sustainable development goals (SDGs): insight from asymmetric and bootstrap Granger causality approaches

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Abstract
We researched China's climate and sustainable development goal with relevant and susceptible instruments capable of inducing and mitigating carbon emissions. Amidst the contributor to the global carbon emissions, China is caught in between mitigating its carbon emission and aiming towards placing its national contribution of emissions to the acceptable levels of 1.5 °C and below 2 °C. Following the intricacies surrounding China's sustainable development as it contains its economic and environmental performance, we adopt China's data of 1980 and 2018 with different scientific approaches (nonlinear autoregressive distributed lag (NARDL), dynamic ordinary least square test, and bootstrap Granger causality) with different instruments (such as economic growth, financial development, renewable energy, and innovation policies) to research China's sustainable development. For clear exposition and insight into our findings with policies attached, we draw a conclusion from the outcomes of the mentioned approaches. From NARDL and dynamic ordinary least squares (DOLS), we find that economic growth through economic activities is statistically significant in determining the trend (increase) of carbon emissions in China in both periods (short run and long run). However, other selected instruments (financial, renewable, and innovation policies) tend towards controlling and moderating the carbon emissions in China. Thus, China has good prospects to mitigate its carbon emissions if considered tailoring its policies towards favorable instruments. From bootstrap Granger causality, we find similar inferential results that support previous findings thereby confirming the positive implication of the selected instruments to China's sustainable development. Hence, the nexus that is established among the selected instruments clearly show the importance of technological innovation and renewable energy in mitigating carbon emissions.

Keywords Economic growth · Technological innovation · Renewable energy · Financial development · NARDL · Bootstrap granger causality · China's sustainable development

Introduction

Environmental degradation is a significant threat that exists around the globe and it is a key driver of climate change. Because of its impact on global warming and potential to disrupt the global carbon cycle, subject of environmental degradation is rapidly gaining the attention of governments across the globe. Climate change is the core issue of this era confronting humanity. Climate change is induced by greenhouse gas emissions (GHGs), primarily carbon dioxide (CO_2) emissions, and this poses unprecedented threats to human progress and survival, including extreme weather, extinction of species, and food scarcity (Dong, et al. 2018).

Consequently, sustainable development has emerged as an area of interest for researchers, academia, industry, and economic and political global leaders. Consequently,

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Highlights of China's carbon mitigation and sustainable development goals (SDGs)
1. This is a China sustainable development study
2. Assessed with dual analysis of symmetric and asymmetric
3. Target is on impact of technology, financial and renewable energy policy
4. China can mitigate CO_2 with renewables, financial and technological innovation
5. Policy is advised to be framed on renewable, financial and innovation

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this triggers the global institutes to established seventeen sustainable development goals (SDGs) embedded with 169 subsidiary objectives forming a centerpiece of the newly established 2030 Agenda of Sustainable Development. The 2030 Agenda of Sustainable Development encompass the environmental, social, and economic aspects of the economies. However, accomplishing these goals will necessitate measures in multiple areas, including technological innovation (Omri 2020; Cancino et al. 2018; Tabrizian et al. 2018), renewable energy (Güney and Kantar 2020; Tiba and Belaid 2020), and financial development (Ziolo et al. 2021; Khan and Qianli 2017).

CO_2 emissions have been caused and impacted by numerous aspects, including a country's income level, financial development (FD), renewable energy consumption (REC), technical innovation (TI), and others. Therefore, preceding research has connected them to economic growth, FD, REC, TI, and GDP (Inglesi-Lotz and Dogan 2018; Fu and Zhang 2017). These indicators are crucial for a country's inclusive sustainability development. Long-term financial development helps economic growth (Goodhart 2004). It might, however, have a positive or negative effect on the environment through increase in carbon emissions (Ali et al. 2018; Khan and Qianli 2017; Goodhart 2004). Kirikkaleli and Adebayo (2021) examined the long-run and causality effect of financial development and renewable energy consumption on environmental sustainability while keeping technical innovation and economic growth under control in a global context. The existence of a long-run relationship between the variables was confirmed by empirical evidence from causality testing. The findings also revealed that global financial development and renewable energy usage have a major positive impact on environmental sustainability in the long run. On the other hand, the findings of Khan and Qianli (2017) and Kirikkaleli and Adebayo (2021) revealed that financial development is an important contributor to restricting CO_2 emissions through effective energy usage.

Porter (1990) believes that the competitiveness of a country depends on the ability of its industry to innovate and modernize. Neglecting the environment's effect for the sake of economic development is unsustainable. There are numerous ways that innovations can have an impact on emissions. Innovation accelerates productivity and economic growth, as well as the transition to low-carbon energy. Innovation increases capital and/or labor productivity. Furthermore, innovation through research and development (R&D) speeds up technological development by allowing for upsurge economic growth while using a similar amount of inputs. Environmental innovation has had a favorable impact on the environmental and economic performance of Korean-owned companies in China (Long et al. 2017). Furthermore, energy transition impacts market efficiency through innovations. It has an impact on market chains and flows. The economy, taxes, subsidies, and regulations are all affected by renewable energy innovation backed by policy enactment. Governments, for example, are increasingly enacting regulations to provoke the utilization of renewable energy throughout the production cycle of companies, which has an impact on market efficiency.

Technological advancements have aided in the growth of renewable energy and have benefitted countries in abating pollutant emissions and in reshaping the quality of their environments through their efforts to maximize their usage of renewable resources. Extensive literature has shown a relationship among innovation and renewable energy sources, as well as their ultimate contribution to economic and environmental developments (Li et al. 2018; Bhattacharya et al. 2016). CO_2 emissions may be reduced by using renewable energy (Long et al. 2015). This is done through transiting from huge amounts of non-renewable energy puts a lot of strain on the ecosystem to a more sustainable energy source. According to Khan et al. (2020), economies are changing their industrial structures to sustainable energy derivatives like renewable energies. These nations pick environmental conservation competencies and ecologically relevant technical advances, which help to enhance ecological protection measures to a certain level. Furthermore, technical advancements have been discovered to aid in the reduction of pollutants and the improvement of environmental protection measures (Long et al. 2017; Shahbaz et al. 2018; Sinha et al. 2020).

China with a 1.4 billion population and with the 2nd highest GDP influence global SDGs through its implementation at a regional level. However, the said factors working simultaneously trigger natural resources exploitation, environmental degradation, and accumulated strain on human wellbeing. China has devised a set of policies and implemented effective strategies to attain those long-term sustainable development objectives (Martí-Ballester 2021). The Chinese government was compelled to prioritize renewable energy investment due to environmental degradation, particularly to address water and air pollution issues. The major reason for the Chinese government's attempt to encourage renewable energy over non-renewable energy consumption (NPC 2005) is to reduce air pollution. Between 1978 and 2017, China saw a tremendous increase in both traditional fossil energy and renewable energy consumption, as well as a change in investment towards renewable energy resources. The Industry Catalog Guiding Foreign Investment 2017 for the Chinese Ministry of Commerce includes renewable energy as an investment sector that encourages international investors to set up entirely foreign businesses in the country (NDRC-ERI 2016). As a result, understanding the dynamic link between economic growth, financial development, renewable energy, and carbon emissions is critical in transforming energy production dynamics.

To this end, the current study attempts to research the ability of China to achieve its sustainable development goals (SDGs) amidst its economic expansion that induces high carbon emissions. China is among the economies that pose a serious threat to global climate conditions through its excessive usage of energy sources which has above 60% of fossil fuels in its energy mix and is capable of increasing greenhouse gas emissions, if they do not undertake ways to mitigate greenhouse gas emissions. This is due to the structure of its economic activities mostly done with excessive utilization of fossil fuels as it includes manufacturing and industrial activities and these activities have direct impact on climate change. China by ranking comes 2nd after the United State of America (USA) in global carbon emissions and this places China as among the contributors and determinants of global atmosphere. Amidst the contributor to the global carbon emissions, China is caught in between mitigating its carbon emission and aiming towards placing its national contribution of emissions to the acceptable levels of 1.5 °C and below 2 °C. China is among the countries that pledge to the Paris Agreement of 2005 of controlling climate change. Following the intricacies surrounding China's sustainable development as it contains its economic and environmental performance, it is interesting to investigate the possible best ways and policies to control its excessive carbon emissions and achieve its climate goals. For effective and insightful research into this objective, we adopt different scientific and theoretical approaches to boost the scientific and technical outcomes of our study. Also, relevant instruments and policies (such as economic growth, financial development, renewable energy, and innovation policies) are applied to assess the ability of China to mitigate carbon emissions and achieve its climate goals. From various studies (Udemba 2021; Alola et al. 2019; Shahbaz et al. 2013), the highlighted instruments have been utilized to study the environmental performance of different countries, and all showed evidence of their (the instruments) implication on environmental performance. Some of the studies (Udemba 2021; Alola et al. 2019; Shahbaz et al. 2013) have proved the validity of the impact of economic and financial development on environmental performance through the environmental Kuznets curve (EKC). Others (Aldieri et al. 2019) have equally shown the environmental implication of technology and innovation. The objective and relevance of this study are presented in a questioning manner as follows: (a) Is economic growth and development through industrial and manufacturing activities a determinant and inducer of China's carbon emissions? (b) Is financial development among the key drivers of China's carbon emissions or mitigating factor to the country's carbon emissions? (c) Is renewable energy policy in China a mitigating force or inducer of its carbon emissions? (d) Is technological innovation through research and development a capable force to mitigate China's carbon emissions? Answers to the above-outlined questions through the scientific estimations and findings will contribute to economic energy and environment nexus literature. Additional research is needed due to the inconsistent and contradictory outcomes of empirical investigations. As a result, utilizing data from 1980 to 2018, this article empirically explores the relationship between CO_2 and renewable energy, technical innovation, financial development, and GDP growth. In order to understand the interrelated questions, e.g., how can renewable energy ameliorate environmental deterioration, a careful examination of the connection between CO_2 emissions, GDP, financial development, RE, and technical innovation in China is required. What relationship exists between CO_2 and GDP? How might technology advancements help to prevent environmental degradation? What is the fallout of financial development on CO_2 emissions? These are all interconnected topics that require an extensive and detailed study of a sample over a long period of time. Furthermore, time domain econometric methods such as the dynamic ordinary least squares (DOLS), FMOLS, GMM, VECM, CCR, CUP-FM, and ARDL were used in the majority of research that looked at these linkages. The current study, on the other hand, will analyze using the nonlinear autoregressive distributed lag (NARDL) econometric technique.

The next sections of this study are structured according to the literature review, data and methodology, empirical results and discussions, and conclusions.

Literature review

Toxic emissions are the source of the environmental threat. Carbon dioxide is one of the major contributors, among others. Technology advancement and innovation may aid in lowering emissions and limiting the negative effects of CO_2 on the environment. In this part, we look at several previous studies that looked at the relationship between CO_2 emissions and GDP, financial development, renewable energy, and technological innovation (TI). Our research divides the evaluated materials into three parts for this aim. In the first section, we discussed economic growth (GDP per capita), renewable energy, and CO_2 emissions. Subsequently, we discussed the nexus among financial development, renewable energy and CO_2 emissions, and the link between both renewable energy, innovations, and CO_2 emissions.

Gross domestic product (GDP), renewable energy (RE), and CO_2 emissions

The association between GDP, energy use, and CO_2 emissions has been extensively researched. Conversely, research on links between GDP, renewables (RE), and CO_2 emissions, on the other hand, is still in its early stages. According to

Adewuyi and Awodumi (2017a, b), between 2009 and 2016, research on GDP, renewable energy (RE), and CO_2 emissions was more profound, particularly in 2014.

As an instance, Wang et al. (2019) conducted research to determine the causation between GDP, CO_2 emissions, and energy consumption in Chinese regions, using a vector autoregressive model embedded with panel data over the period of 1997 to 2015. They conducted a comparative analysis of the eastern part of China and central and western Chinese regions. The findings revealed that in the eastern and central Chinese regions, there is univocal causation between per capita GDP and CO_2 emissions. Meanwhile, in western provinces, there is unidirectional causation between CO_2 emissions and GDP per capita. Lu (2017) investigated the nature of causality between CO_2 emissions, GDP, and REC for 24 Asian areas. He used the Granger causality test, panel cointegration technique, and vector error correction model to analyze data from 1990 to 2012. Their findings revealed a long-run equilibrium between renewable energy consumption, carbon emissions, and GDP. A univocal causality was identified moving from GDP to CO_2 emissions, whereas bidirectional causality was identified between CO_2 emission and renewable energy and among renewable energy and GDP. For Tunisia, investigate the link between CO_2 emissions, GDP, renewable energy use, and trade. The data utilized by Jebli and Youssef (2015) covered the years 1980 to 2009. They used the ARDL bounds testing method to see if there was any causation between the variables. They identified the existence of short-run unidirectional causation between GDP, CO_2 emissions, and renewable energy based on the statistical results of their research.

Similarly, between 1990 and 2011, Attiaoui et al. (2017) analyzed the impact of income development, energy usage, and CO_2 pollutions in renewables of 22 African countries. It was pointed out that if CO_2 is negative, GDP has no effect on renewable energy consumption, and that conventional fossil fuels have a positive influence on renewable energy consumption. Kivyiro and Arminen (2014), on the other hand, utilized panel data to investigate the causation between CO_2 emissions, GDP, energy usage, and FDI in Congo, Kenya, South Africa, Zimbabwe, and Zambia. They used the ARDL bound testing econometric approach to do this, and data from 1971 to 2009 were used. They discovered that there is one-way causation from other factors to CO_2 emissions. They find that shifting the causation from all other factors to CO_2 exposes itself in the locations where the EKC hypothesis holds true. For Turkey, Yavuz (2014) looked at the long-term connection and causation between CO_2 emissions, per capita income, and energy use. He utilized the Johansen cointegration test using data from 1960 to 2007 to determine the relationship between the variables. Their findings, based on econometric data, indicated the existence of long-term association among CO_2 emissions, per capita income, and energy consumption; moreover, their findings corroborate the legitimacy of the environmental Kuznets curve hypothesis (EKC) in the short and long run. Similarly, Sebri and Ben-Salha (2014) used data from 1971 to 2010 to examine the BRICS bloc nations. To obtain reliable findings, they employed the ARDL bound testing technique. They discovered a bidirectional causal link between GDP and renewable energy based on econometric estimates, suggesting the relevance of renewable energy as a provoking element to boost GDP.

Financial development, renewable energy, and CO_2 emissions

Notwithstanding the diverse effects of technological breakthroughs and FDI, financial development may have a substantial impact on the sustainable energy sector. Projects using renewables are inherently connected with high prices. They demand a large amount of start-up capital, constant innovation through research (R&D) investment, and long-term debt settlements (Sonntag-O'Brien and Usher 2006). In comparison to developed financial mechanisms, which may assist expand the renewable energy industry in an effective manner, an underdeveloped financial system can hinder the promotion of renewable energy businesses even when demand is strong Eren et al (2019). There have only been a few studies that have looked at this topic. Rasoulinezhad and Saboori (2018) discovered that liberalization via trade and growth are important drivers of renewables use in this situation. Similarly, Eren et al. (2019) found that the influence of economic and monetary growth are the major factors to exacerbate renewables use in India from 1971 to 2015. These findings also suggest that a developed financial position in any country or area may offer funding to shift from renewable to non-renewable energy industries.

Ali et al. (2018) used data from 1995 to 2015 to investigate the dynamic relationship between total reserves, financial development, renewable energy use, and trade openness for a panel of 19 Asian nations. They found the existence of long-run causality among the said variables in almost all income group countries. Khan and Qianli (2017) investigated the link between renewable and non-renewable energy consumption, agricultural land utilization, and greenhouse gas emissions for Pakistan using Toda and Yamamoto's methodology. They found unidirectional causality between renewable energy utilization and GHG emissions. The FMOLS and cointegration regression indicated that using renewable energy reduced GHG emissions by 1.086%. Lin et al. (2016), for example, found a cointegration connection between financial expansion and utilization of renewable energy in order to discover the variables that influence Chinese renewable energy utilization. The findings revealed that financing has a favorable influence on renewables, but liberalization and energy use have a negative impact on China's usage of renewable energy. Khan and Qianli (2017) examined the long-run correlation among greenhouse gases (GHGs), financial development, improved sanitation, renewable energy, and trade and forest for a set of 24 countries of different income groups over the period of 1990 to 2015. They explored bidirectional causality among financial development and forest (Asia), energy use and renewable energy, and forest for the Asian region. They further identified one-way causality running from financial development to GHG for the US region, energy to GHG for the Asian region, renewable energy to GHG for the US region, GHG to financial development for the European region, and GHG to energy for Europe, US, and Africa.

Godil et al. (2020) investigated the impact of financial development, technological innovation, and corporate quality on CO_2 emissions in Pakistan. They revealed that financial development and technological innovation have a negative impact on CO_2 emissions notwithstanding emission intensity, indicating that both explanatory variables can participate in CO_2 emissions mitigation. For the years 1995 to 2010, Ba Sarr and Akr (2015) examined the connections between CO_2 emissions, energy use, financial development, and tourism in France, Greece, Italy, Spain, and Turkey. According to the data, energy utilization upsurges by 1% causing the increase in CO_2 emissions by 3.02%, whereas financial development upsurge by 1% reduces CO_2 emissions by 0.12% and 0.11%, respectively. Furthermore, the causality study revealed a unidirectional causal link between visitor numbers and economic development, as well as a bidirectional interaction between CO_2 emissions, financial growth, energy, and visitors. Using the second generation of econometric methods, Iorember et al. (2020) defined the causality among renewable, financial liberalization, and CO_2 emission. Granger causality based on the VECM was used to investigate one-sided causality moving from financial liberalization to CO_2 pollutions and from CO_2 pollutions to renewables, but no association was found between financial liberalization and renewables. Ali et al. (2018) used VECM Granger causality to examine the causal link between renewable energy and financial development. Their findings were similar for panels from diverse income levels throughout the world. Hassine and Mathieu (2020) presented the GCC causative results from 1980 to 2012, which included a unidirectional causality moving from renewables to private credit-based financial liberalization. Their findings backed up the long-term link between financial liberalization and renewables. According to research from Gozgor et al. (2020) CO_2 emissions, growth, and oil costs are all major constructive drivers of renewable energy use in OECD nations,

Renewable energy, innovations, and CO_2 pollutions

Over the last two decades, there has been a lively discussion about the rapid development of renewable energy and its influence on environmental quality and economic progress (Moutinho et al. 2017; Kahia et al. 2017). Several studies have looked at the influence of renewable and non-renewable energy use, as well as technical innovation and GDP, on CO_2 emissions. Studies on renewable energy determinants, on the other hand, are few and have yet to be discovered empirically. Several studies have looked at several aspects to see what influence they have in renewable energy; Razzaq et al. (2021), for example, investigated the interconnections between green technological innovation and carbon emissions (consumption-based and land emissions) in BRICS nations. The findings revealed that in Brazil, China, India, and Russia, the emissions-mitigating effect of green technological innovation is only pronounced at higher emissions quantiles, but at lower emissions quantiles, green technological innovation is neutral or positively related to carbon emissions. Ahmad et al. (2021) investigated symmetric and asymmetric effects and discovered that patent has negative short-run symmetric impacts on carbon emissions in Pakistan. Alam and Murad (2020) found that technical innovation and economic growth have a mixed influence on OECD nations' renewables use. Omri (2020) explored the influence of technological innovation on the three pillars of sustainable development for low-, middle-, and high-income nations and deduced that technological innovation contributes simultaneously to the three pillars of sustainable development only in the case of rich countries. Yu and Du (2019) also came to the conclusion that China's self-innovation is a cause of environmental deterioration. Santra (2017) discovered that while innovations have a substantial influence on economic development, they are not trustworthy for environmental improvement. Studies such as Fisher-Vanden et al. (2004), which showed adverse impacts on energy utilization, have claimed that technical advances are required to attain energy efficiency, leading in the increased awareness of renewables, suggesting that innovations can help China improve its energy efficiency. Hang and Tu (2007) found that escalating non-renewable prices may be an effective approach to attaining energy effectiveness when examining energy force and pricing statistics in China. Between 1980 and 2010, Geng and Ji (2016) consistently found a long-run convergence among innovation and renewables for a selection of six major industrialized nations. Their findings backed up bidirectional causal relationships. According to Yu and Du (2019), independent innovation initiatives have played a significant influence in China's CO_2 emissions reduction. According to Brandão Santana et al. (2015), technical innovation has aided the establishment of an efficient energy market while also allowing for long-term economic growth throughout the BRICS and G7 nations. Yii and Geetha (2017) found a causal relationship between technical advances, growth, energy consumption, energy costs, and CO_2 emissions in Malaysia from 1971 to 2013. The findings revealed that technical progress has contributed to a decline in CO_2 emissions in the short run, despite the absence of a long-term link. Azevedo et al. (2018) looked at the amount of CO_2 emissions in relation to GDP and emissions delays for the BRICS economies from 1980 to 2011 and classified the nations into two categories based on CO_2 emissions heterogeneity. Despite the fact that empirical data suggests that GDP growth and CO_2 emissions are the major drivers of CO_2 emissions variations, the authors observed conflicting results for the impact of economic activity on CO_2 emissions across nations. The authors stated that advances in innovation and member countries' understanding of energy savings will be critical in decreasing CO_2 emissions. Aldieri et al. (2018) backed the innovation accounting for lower CO_2 emissions in OECD countries. Su and Moaniba (2017), on the other hand, argue that the mixed results and empirical data demonstrating the negligible influence of innovation and/or climate-related technology on CO_2 emissions must be taken into account. Raiser et al. (2017) showed that patents appear to hinder development and are viewed as a barrier to climate change mitigation, which is consistent with this premise.

We discovered that the influence of GDP, FD renewable energy, and innovations on the environment is widely investigated; however, the acquired conclusions are equivocal, after evaluating a large body of empirical literature. As a result, additional research is needed to reduce the debate over GDP, foreign direct investment, renewable energy, and creativity. The objective and relevance of this study as presented in the introductory section align with the contribution of the study anchored on economic energy and environment nexus literature. Additional research is needed due to the inconsistent and contradictory outcomes of empirical investigations Furthermore, Hatemi-j (2012) causality test and the NARDL are utilized in this study as statistical techniques to determine compelling cointegration between variables. Sertoglu et al. (2021) and Doganlar et al. (2021) applied Hatemi-j (2012) causality test model in their studies in order to test the causal relationship among investigated variables. As a result, the goal of this study was to give important policy recommendations based on the aforementioned goals.

Data and methodology

As was mentioned in the introduction section, this study aims to assess the symmetric and asymmetric effect of financial development and technological innovation on China's environmental performance. In doing so, carbon dioxide (CO_2) emission level is used as a dependent variable to indicate the environmental quality. This indicator was described as a function of economic performance, financial development, renewable energy, and technological innovation as follows:

$$CO_2 = f(\text{EGP}, \text{FD}, \text{RE}, \text{INN}) \quad (1)$$

Moreover, the general representation of this function can be shown as follows:

$$lnCO_{2t} = \alpha_0 + \beta_1 lnEGP_t + \beta_2 lnFD_t + \beta_3 lnRE_t + \beta_4 lnINN_t + \varepsilon_t \quad (2)$$

where CO_2 represents environmental quality and is measured in kilogram per 2010 US$ of gross domestic product (GDP), EGP indicates the economic performance of China and measured in per capita real GDP in 2010 constant US dollar, FD is used as financial development and measured as domestic credit to the private sector as a percentage of GDP, RE depicts for renewable energy use and measured as a share of total energy use, and finally, INN signifies technological innovation level in China and measured as total trademark application. To examine the symmetric and asymmetric effect of these explanatory variables on environmental quality, the sample period covered the period from 1980 to 2018, on an annual basis. The data for all variables, except renewable energy use, was obtained from World Bank World Developing indicators (WDI) and renewable energy data was gathered from the British Petroleum Statistical Review of World Energy (bp.com) (2021). To get more robust results, the variables are converted into their logarithmic forms which allow us to reduce the heterogeneity in data and improve normality in their distribution.

The variables and their measurements as utilized in this study are defined and summarized in Table 1.

Source: Compiled by the authors

Moreover, in order to examine the applicability of the models, at the first phase, the unit root tests were utilized. Then, dual empirical analysis with both symmetric (DOLS (dynamic ordinary least squares)) and asymmetric (NARDL (nonlinear autoregressive distributed lag)) models was employed. The NARDL model can decompose the positive and negative shocks of the explanatory variables on dependent variables. Also, nonlinear autoregressive distributed lag model (NARDL) was employed to capture the systematic adjustment of the variables and their asymmetric relationships with environmental quality in China. The NARDL model, developed by Shin et al. (2014), can separate the shocks and capture the effects of positive and negative changes on explanatory variables. It can also eradicate the problems caused by endogeneity and serial correlations in estimation. Thus, the shocks of

Table 1 Summary of the data and variables utilized in our study

Instruments/variables	Short form	Measurements	Sources
Carbon dioxide emissions represent environmental quality	CO_2	Measured in kilogram per 2010 US$ of gross domestic product (GDP)	World Bank World Developing indicators (WDI)
Economic performance of China	EGP	Measured in per capita real GDP in 2010 constant US dollar	World Bank World Developing indicators (WDI)
Financial development	FD	Measured as domestic credit to private sector as percentage of GDP	World Bank World Developing indicators (WDI)
Renewable energy use	RE	Measured as a share of total energy use	British Petroleum Statistical Review of World Energy (bp.com) (2021)
Technological innovation level in China	INN	Measured as total trademark application	World Bank World Developing indicators (WDI)

explanatory variables in Eq. 2 can be decomposed and represented as follows.

$$\begin{aligned}\Delta \ln CO_{2t} &= \eta_0 + \theta_1 \ln CO_{2t-1} + \beta_2 lnEGP_t^+ + \beta_3 lnEGP_t^- + \phi_4 lnFD_t^+ \\ &+ \phi_5 lnFD_t^- + \varphi_6 lnRE_t^+ + \varphi_7 lnRE_t^- + \chi_8 lnINN_t^+ + \chi_9 lnINN_t^- \\ &+ \sum_{j=1}^{n-1}(\gamma_1 \Delta \ln CO_{2t-1}) + \sum_{j=0}^{n_2}(\mu_j \Delta \ln EGP_{t-j}^+ + \mu_j \Delta \ln EGP_{t-j}^-) \\ &+ \sum_{j=0}^{n_3}(\pi_j \Delta \ln FD_{t-j}^+ + \pi_j \Delta \ln FD_{t-j}^-) + \sum_{j=0}^{n_4}(\omega_j \Delta \ln RE_{t-j}^+ \\ &+ \omega_j \Delta \ln RE_{t-j}^-) + \sum_{j=0}^{n_4}(\psi_j \Delta \ln INN_{t-j}^+ + \psi_j \Delta \ln INN_{t-j}^-) + \upsilon_t\end{aligned} \tag{3}$$

where η_0 α_0 depicts intercepts, and + and − signs on the explanatory variables signify the positive and negative shocks. Moreover, υ_t depicts the error term in time t and Δ is used to represent the short-term effect of the variables. In this regression, the lagged dependent variable has been used to get the robust and accurate parameter estimates, as well as to eliminate substantive coefficient collapse and the first order of autocorrelation problem. Adding the lagged dependent variable will also lead to minimizing the possibility of severe bias in estimation. (Keele and Kelly 2006) Besides, the short-term association of explanatory variables with a dependent variable can be extended with ECT_t in NARDL framework which is used to test the speed of adjustment to long-run steady-state point between investigated variables and presented in the equation below.

$$\begin{aligned}\Delta \ln CO_{2t} &= \eta_0 + \sum_{j=1}^{n-1}(\gamma_1 \Delta \ln CO_{2t-1}) + \sum_{j=0}^{n_2}(\mu_j \Delta \ln EGP_{t-j}^+ + \mu_j \Delta \ln EGP_{t-j}^-) \\ &+ \sum_{j=0}^{n_3}(\pi_j \Delta \ln FD_{t-j}^+ + \pi_j \Delta \ln FD_{t-j}^-) + \sum_{j=0}^{n_4}(\omega_j \Delta \ln RE_{t-j}^+ + \omega_j \Delta \ln RE_{t-j}^-) \\ &+ \sum_{j=0}^{n_4}(\psi_j \Delta \ln INN_{t-j}^+ + \psi_j \Delta \ln INN_{t-j}^-) + \Theta ECT_{t-1} + \upsilon_t\end{aligned} \tag{4}$$

On the other hand, as suggested in Mujtaba and Jena (2021) study, the positive and negative shocks of explanatory variables can be decomposed as follows:

$$lnEGP_t = lnEGP_0 + lnEGP_t^+ + lnEGP_t^- \tag{5}$$

$$lnFD_t = lnFD_0 + lnFD_t^+ + lnFD_t^- \tag{6}$$

$$lnRE_t = lnRE_0 + lnRE_t^+ + lnRE_t^- \tag{7}$$

$$lnINN_t = lnINN_0 + lnINN_t^+ + lnINN_t^- \tag{8}$$

where $\ln EGP_0$, $\ln FD_0$, $\ln RE_0$, and $\ln INN_0$ present the initial random value of the variables. Also, $lnEGP_t^+ + lnEGP_t^-$,$lnFD_t^+ + lnFD_t^-$, $lnRE_t^+ + lnRE_t^-$, and $lnINN_t^+ + lnINN_t^-$ accrue positive and negative shocks, respectively, and signify partial sum process in estimation. This process can also be defined as follows:

$$lnEGP_t^+ = \sum_{j=1}^{t} \Delta lnEGP_j^+ = \sum_{j=1}^{t} max(\Delta lnEGP_j, 0), lnEGP_t^- = \sum_{j=1}^{t} (\Delta lnEGP_j, 0) + \varepsilon_t \tag{9}$$

$$lnFD_t^+ = \sum_{j=1}^{t} \Delta lnFD_j^+ = \sum_{j=1}^{t} max(\Delta lnFD_j, 0), lnFD_t^- = \sum_{j=1}^{t} (\Delta lnFD_j, 0) + \varepsilon_t \tag{10}$$

$$lnRE_t^+ = \sum_{j=1}^{t} \Delta lnRE_j^+ = \sum_{j=1}^{t} max(\Delta lnRE_j, 0), lnRE_t^- = \sum_{j=1}^{t} (\Delta lnRE_j, 0) + \varepsilon_t \tag{11}$$

$$lnINN_t^+ = \sum_{j=1}^{t} \Delta lnINN_j^+ = \sum_{j=1}^{t} max(\Delta lnINN_j, 0), lnINN_t^- = \sum_{j=1}^{t} (\Delta lnINN_j, 0) + \varepsilon_t \tag{12}$$

Furthermore, the significance of long-run symmetric ($\gamma^+ = \gamma^-$) and asymmetric ($\gamma^+ \neq \gamma^-$) relationship of the variables was tested with the WALD test. The effects of asymmetric cumulative dynamic multipliers on dependent variable of a unit change in positive and negative shocks of explanatory variables can be developed as follows.

$$m_h^+ = \sum_{j=0}^{h} \frac{\delta \ln CO_{2t+j}}{\delta \ln EGP_{t-1}^+}, m_h^- = \sum_{j=0}^{h} \frac{\delta \ln CO_{2t+j}}{\delta \ln EGP_{t-1}^-},$$
$$m_h^+ = \sum_{j=0}^{h} \frac{\delta \ln CO_{2t+j}}{\delta \ln FD_{t-1}^+}, m_h^- = \sum_{j=0}^{h} \frac{\delta \ln CO_{2t+j}}{\delta \ln FD_{t-1}^-}, \quad h = 0, 1, 2, 3... \quad (13)$$
$$m_h^+ = \sum_{j=0}^{h} \frac{\delta \ln CO_{2t+j}}{\delta \ln RE_{t-1}^+}, m_h^- = \sum_{j=0}^{h} \frac{\delta \ln CO_{2t+j}}{\delta \ln RE_{t-1}^-},$$
$$m_h^+ = \sum_{j=0}^{h} \frac{\delta \ln CO_{2t+j}}{\delta \ln INN_{t-1}^+}, m_h^- = \sum_{j=0}^{h} \frac{\delta \ln CO_{2t+j}}{\delta \ln INN_{t-1}^-},$$

where $h \to \infty$, $m_h^+ \to \xi^+$, and $m_h^- \to \xi^-$, where ξ^+ and ξ^- are accounted as $\xi^+ = -\beta^+/\rho$ and $\xi^- = -\beta^-/\rho$, respectively.

Additionally, dynamic ordinary least squares model was utilized to test the consistency of the results and stability, consistency of the coefficient, and goodness of fit of NARDL model were examined by utilizing CUSUM (cumulative sum of recursive residuals) and CUSUMsq (cumulative sum of recursive residuals squares) stability tests. Lastly, Hatemi-J (2012) leveraged bootstrap causality test was employed to test the causal relationship among investigated variables. This model allowed us to get robust results with small sample size and uses bootstrap distributions to minimize the size of distortions in series. Meanwhile, to the best knowledge of the authors, none of the studies yet used this technique to investigate the causal relationship among investigated variables for China. This can be emphasized as one of the main contributions to the existing literature.

Moreover, with the guidance of Sertoglu et al. (2021) and Doganlar et al. (2021), in order to test the causal relationship among investigated variables, Hacker and Hatemi-J (2012) model practices vector autoregressive model VAR (p) given below to acquire the results.

$$x_t = a + B_1 x_{t-1} + \cdots + B_p x_{t-p} + v_t \quad (14)$$

where the dimensional vectors ($n \times 1$) are represented with a v_t and x_t. Also, the $n \times n$ dimensional parameter matrix is represented as B_i (where $i \geq 1$) in Eq. 14.

Additionally, this model emphasizes an alternative formulation for lag length selection (Eq. 15), with respect to the combination of Hannan-Quinn and Schwarz information criteria. This formula was called as Hatemi-J information criterion (HJC).

$$\mathrm{HJC} = \ln(\det\hat{\vartheta}_j) + j\left(\frac{n^2 \ln S + 2n^2 \ln(\ln S)}{2S}\right) \quad j = 0, 1, 2, ...p \quad (15)$$

In Eq. 15, the factor of the anticipated maximum likelihood variance–covariance matrix of error term in the VAR (j) model was represented by $\det\hat{\vartheta}_j$. The natural logarithm form was symbolized as Ln and number of variables were represented by n and S was used for sample size (Hatemi-J and Uddin 2014).

Empirical findings and discussion

This section provides the results of estimations obtained from employed methodologies. As mentioned in the previous section, the applicability of the models and the integration order of the series was tested by employing augmented Dickey and Fuller (1979) and Phillips and Perron (1988) unit root tests. The results are presented in Table 2 and indicate that all investigated variables are stationary at their first differenced form. In other words, the shocks on each variable are permanent and they are stationary at integrated order 1, $I(1)$.

Moreover, the long-run steady-state association among investigated variables was tested by the NARDL bounds test. The result shows that the calculated test statistic (4.1454) is greater than the upper bound (3.50) of the test at a 5% significance level. Thus, we can reject the null hypothesis of no cointegration relationship among investigated variables and confirm the long-run steady-state association among them (Table 3).

Furthermore, once the long-run steady-state association among investigated variables was identified and the precondition of applicability of the model was satisfied, the estimation process was furthered with NARDL method. Thus, the magnitude and direction of the effect of the positive and negative shocks on explanatory variables on the environmental quality level were examined. The results are presented in Table 4 and prove that all explanatory variables have a statistically significant effect on the dependent variable and can be accounted as the determinants of environmental quality in China.

In detail, the coefficient of ECT (− 1) is negative and statistically significant at a 1% significance level. This reveals that 75.2% of disequilibrium in environmental quality level in the short run can be restored in the long run with these independent variables. On the other hand, the long-run

Table 2 Stationarity test results

Variables	*ADF*		*PP*	
	Level	Δ	Level	Δ
CO_2	− 1.042	− 3.572**	0.947	− 4.647***
EGP	− 0.798	− 4.166***	0.525	− 3.483**
FD	− 1.374	− 5.716***	− 1.471	− 5.871***
RE	− 0.119	− 7.119***	− 0.046	− 7.257***
INN	0.918	− 5.239***	0.911	− 5.269***

All variables were tested with only intercept

* stands for significant at 10 percent

** stands for significant at 5 percent

*** stands for the significance level at 1%

Source: Authors' computation

Table 3 Bound test results

K	Calculated F-stat	1%		5%		10%	
		B_L	B_U	B_L	B_U	B_L	B_U
7	4.1454	2.96	4.26	2.32	3.50	2.03	3.13

B_U upper critical bound, B_L lower critical bound

Source: Authors' computation

Table 4 Estimation output

Var	Coeff	Std. error	t-Stat	P-value
Short-run coefficients				
D(LNEGP⁺)	1.950***	0.296	3.335	0.0000
D(LNEGP⁻)	−0.177**	0.155	−4.145	0.0268
D(LNFD⁺)	−0.164**	0.224	−3.734	0.0470
D(LNFD⁻)	0.470*	0.270	1.740	0.0951
D(LNRE⁺)	−0.552***	0.126	−4.351	0.0002
D(LNRE⁻)	0.541**	0.775	2.698	0.0492
D(LNINN⁺)	−0.173***	0.053	−3.268	0.0056
D(LNINN⁻)	0.124**	0.166	2.751	0.0460
ECT(−1)	−0.752***	0.089	−8.398	0.0000
Long-run coefficients				
LNEGP⁺	1.246***	0.830	6.317	0.0000
LNEGP⁻	−0.334***	0.576	−4.243	0.0008
LNFD⁺	−0.218**	0.281	−1.777	0.0446
LNFD⁻	0.911***	0.271	3.359	0.0047
LNRE⁺	−0.488**	0.173	−2.086	0.0322
LNRE⁻	0.437**	0.905	1.587	0.0126
LNINN⁺	−0.718***	0.114	−6.289	0.0000
LNINN⁻	0.365*	0.197	1.853	0.0849
C	2.036***	0.653	4.263	0.0008

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

Source: Authors' computation

coefficients of decomposed economic performance with positive and negative shocks are statistically significant at a 1% significance level and calculated as 1.245 and −0.334, respectively. These suggest that a 1% rise in economic performance in China is expected to decline the environmental quality level by 1.246%, while a 1% reduction in economic performance will improve environmental quality by 0.334%, on average. These values were accounted as 1.95 and 0.177 for the positive and negative shocks in the short run, respectively. These values show that increasing economic performance and prioritizing the economic growth to environment in China will lead to higher CO_2 emissions and greater degradation to the environment. These findings support the findings from Wang et al. (2019) for China, Udemba (2019) for China, Udemba (2021) for Chile, and Lu (2017) for China. Thus, the government or policymakers should pursue the policies to maintain the environmental quality by imposing more carbon taxes on production and supporting the sectors to transform their traditional high CO_2 emitter technologies into environmentally friendly technologies to sustain the environmental quality. Moreover, China should develop some rules/policies for domestic/foreign investors to act environmentally friendly and invest with environmentally friendly technologies. Concerning financial development, a statistically significant association with environmental quality was found from the positive and negative shocks on both terms. The results imply that a 1% increase in financial development is expected to decrease the CO_2 emission by 0.164% in the short run and 0.218% in the long run, on average. However, a 1% increase in negative shocks in financial development will contribute to the degradation level of the environment by 0.47% in the short run, while this was accounted as 0.911% in the long run, on average. This proves that the more easy access to finance will cause to improve the purchase of environmentally friendly technologies and may improve the environmental awareness to act environmentally friendly. Our findings with regards to financial development correspond to the findings of Eren et al. (2019) for India, Lin et al. (2016) for 74 global, and Rasoulinezhad and Saboori (2018) for the Commonwealth of Independent States (CIS) region. Furthermore, a 1% increase in the share of renewable energy sources in total energy consumption will contribute to the environmental quality by 0.552% in the short run and this value was accounted as 0.541% in the long run. However, a 1% decrease in the use of renewable energy in China will degrade the environmental quality by 0.488% and 0.437% in the short run and long run, respectively. Our findings with regards to renewable energy correspond to the findings of Alam and Murad (2020) for OECD, Moutinbo and Robaina (2016), and Kahia et al. (2017). To this end, government should increase its financial support on installation of renewable energy technologies as well as pursue some policies to remove the limitations on the use of renewable energy sources. Thus, it will improve and sustain the environmental quality as well as reduce the dependency on traditional energy use. This will also contribute to the government budget since the oil import dependency will reduce by using domestic energy sources. Lastly, the coefficients of technological innovation demonstrate that a 1% increase (decrease) in technological innovations improves (degrade) environmental quality by 0.173% (0.124%) in the short run, whereas these values were calculated as 0.718% and 0.365%

Table 5 DOLS estimation output

Var	Coeff	Std. Error	t-Stat	*P*-value
LNEGP	1.251*	1.892	2.661	0.0513
LNEGP^2	−0.038**	0.037	−2.026	0.0312
LNFD	−0.587**	0.250	−2.345	0.0254
LNRE	−0.660**	0.295	−2.234	0.0326
LNINN	−0.067**	0.106	−3.634	0.0153
C	−4.983***	0.987	−2.199	0.0084
R-squares: 0.972		Adjusted R-squared		0.967

***, **, and * indicate 0.01, 0.05, and 0.10 significance levels, respectively

Source: Authors' computation

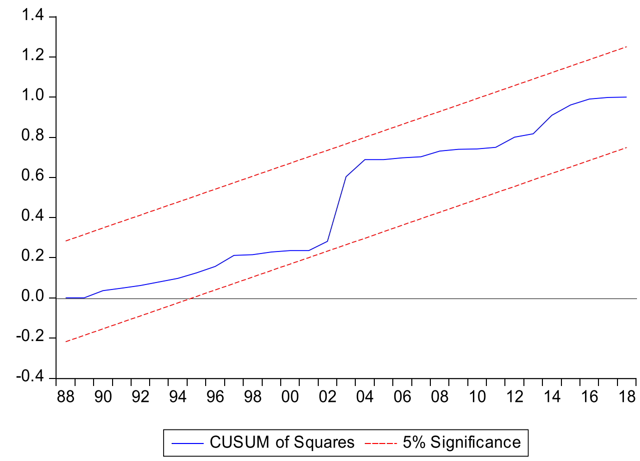

Fig. 2 CUSUMSQ test result

for the long run, on average. Our findings with regards to innovation correspond to the findings of Alam and Murad (2020) for OECD, Yu and Du (2019) for China, and Santra (2017) for Bali Island. This suggests that innovation through research and development (R&D) is capable of mitigating environmental degradation if pursued to be among the policies to abate carbon emissions by the Chinese authorities.

Table 5 gives the details of the outcome for the DOLS model which was used for confirming the NARDL model. The signs of the coefficients are the same for both models and all the variables are statistically significant at different significance levels. Therefore, the consistency of the estimation output of NARDL was confirmed. The output of DOLS shows that all selected explanatory variables are statistically significant determinants of the environmental quality of China and a 1% rise in economic performance in the path of being a developed country will degrade the environment by 1.251% in the long run, on average. Moreover, the coefficient of the square of the economic performance is negative and significant. This indicates that the inverted U-shaped environmental Kuznets curve hypothesis is valid for the Chinese economy. Thus, every 1% rise in the economic performance will lead to emit more carbon dioxide to the environment and increase it by 1.251% up to the threshold level, but after this level, every 1% rise in economic performance will improve the environmental quality by 0.038%, on average. To this end, the government should prioritize the environment to have better environmental conditions. Together with, a 1% rise in financial development and making it easier to reach the money will reduce the CO_2 level and better off the environment by 0.587%, on average. Moreover, a 1% increase in renewable energy will improve environmental quality by 0.66% and this value was calculated as 0.067% for technological innovation in China, on average.

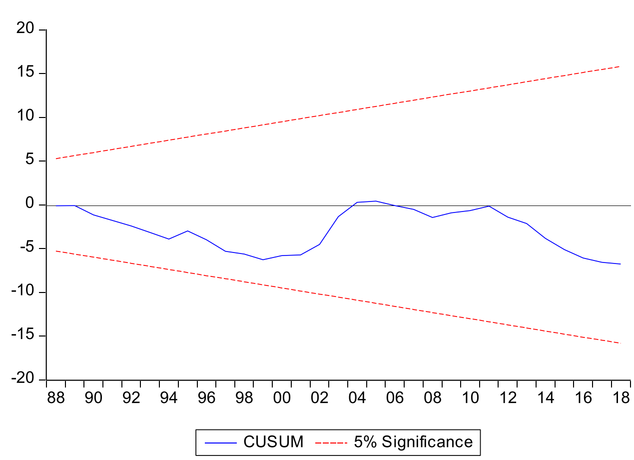

Fig. 1 CUSUM test result

As discussed above, CUSUM (Fig. 1) and CUSUMsq (Fig. 2) stability test (Brown et al. 1975) results were given. These results assert the stability of estimated coefficients since the calculated statistics are within the 5% significance level for both tests.

Table 6 shows the results of bootstrap leverage causality test results suggested by Hacker and Hatemi-J (2012). The null hypothesis of no causal relationship among variables can be rejected if the calculated Modified WALD (MWALD) test statistic is greater than bootstrap critical values. The outcome of the test demonstrates the feedback causal association of environmental quality with economic performance and financial development. This finding aligns with the finding from Wang et al. (2019) for the case of China. Bidirectional causal association were found among technological innovation and financial development. Moreover, technological innovation also has another bidirectional causal relationship with economic performance in China. However, the unidirectional causal association runs to environmental quality from renewable energy and innovation. This is in agreement with the findings from Jebli and Youssef (2015). Lastly, other unidirectional causal relationships

Table 6 Hacker and Hatemi-J (2012) test results

Variables	Var (*p*)	MWALD	Critical values (bootstrap)			Decision
			1%	**5%**	**10%**	
$\ln CO_2 \rightarrow \ln EGP$	1	5.287**	8.097	4.441	3.040	CO_2 and EGP have bidirectional causal relationship
$\ln EGP \rightarrow \ln CO_2$	1	8.179***	7.957	4.334	2.943	
$Ln CO_2 \rightarrow \ln FD$	1	4.129**	7.628	4.059	2.864	CO_2 and FD have bidirectional causal relationship
$Ln FD \rightarrow \ln CO_2$	1	6.139**	8.001	4.302	3.004	
$\ln CO_2 \rightarrow \ln RE$	1	0.063	7.749	4.687	3.068	RE causes CO_2 emission
$Ln RE \rightarrow \ln CO_2$	1	3.204*	8.162	4.483	3.090	
$\ln CO_2 \rightarrow \ln INN$	1	0.208	7.992	4.303	2.965	INN causes CO_2 emission
$Ln INN \rightarrow \ln CO_2$	1	3.583*	8.170	4.390	3.077	
LnEGP → lnFD	1	0.696	7.278	4.117	2.920	Financial development causes Economic performance
LnFD → lnEGP	1	5.484	7.461	4.191	2.915	
LnEGP → lnRE	1	0.177	7.349	4.126	2.934	No causal relationship
LnRE → lnEGP	1	2.937	8.311	4.409	3.040	
lnEGP → lnINN	1	6.594**	7.721	4.322	2.903	EGP and INN have bidirectional causal relationship
LnINN → lnEGP	1	4.501**	7.459	4.184	2.944	
LnFD → lnRE	1	0.091	7.905	4.426	2.994	No causal relationship
lnRE → lnFD	1	1.838	7.252	4.177	2.881	
LnFD → lnINN	1	6.005	7.686	4.242	2.905	FD and INN have bidirectional causal relationship
lnINN → lnFD	1	3.018*	7.485	4.334	2.985	
lnRE → lnINN	1	0.038	7.673	4.254	2.950	RE and INN have unidirectional causal relationship
LnINN → lnRE	1	4.711**	7.507	4.209	2.981	

(1) 1%, 5%, and 10% significance levels are indicated with *, **, and ***, respectively

(2) HJC information criteria were used for the optimal lag length determination

(3) Critical values were acquired by 10.000 replications (bootstrap)

Source: Authors' computation

were investigated that run from technological innovation to renewable energy and financial development to economic performance. This finding is in agreement with the findings from Lu (2017) for Asian Areas.

Conclusion and policy recommendation

This is a country-specific research of China's climate and sustainable development goal. Economies such as China by all means pose a serious threat to global warming if they do not undertake ways to mitigate greenhouse gas emissions. This is due to the structure of its economic activities mostly done with excessive utilization of fossil fuels as it includes manufacturing and industrial activities and these activities have a direct impact on climate change. China is ranked 2nd after the United State of America (USA) in global carbon emissions. Amidst the contributor to the global carbon emissions, China is caught in between mitigating its carbon emission and aiming towards placing its national contribution of emissions to the acceptable levels of 1.5 °C and below 2 °C. China is among the countries that pledge to the Paris Agreement of 2005 of controlling climate change. Following the intricacies surrounding China's sustainable development as it contains its economic and environmental performance, it is interesting to investigate the possible best ways and policies to control its excessive carbon emissions and achieve its climate goals. Hence, we adopt different scientific approaches (nonlinear autoregressive distributed lag-NARDL, dynamic ordinary least square test, and bootstrap Granger causality) with different instruments (such as economic growth, financial development, renewable energy, and innovation policies) to research China's sustainable development. For clear exposition and insight into our findings with policies attached, our emphases are on the outcomes of the mentioned scientific approaches. From NARDL and DOLS, we find that economic growth through economic activities is statistically significant in determining the trend (increase) of carbon emissions in China in both periods (short run and long run). The good part of findings from NARDL and DOLS is that other selected instruments (financial, renewable, and innovation policies) tend towards controlling and moderating the carbon emissions in China. Thus, China has good prospects to mitigate its carbon emissions if considered tailoring its policies towards the favorable instruments. From bootstrap Granger causality, we find similar inferential results that support the findings from both NARDL and DOLS thereby confirming the positive implication of the selected instruments to China's sustainable development. Hence, bidirectional causal association was found between technological innovation and financial development. Technological innovation also has another bidirectional causal relationship with economic performance in China. However, the unidirectional causal association runs to environmental quality from renewable energy and innovation. Lastly, other unidirectional causal relationships were investigated that run from technological innovation to renewable energy and financial development to economic performance. The nexus that is established among the selected instruments clearly show the importance of technological innovation and renewable energy in mitigating carbon emissions.

Findings from the adopted approaches clearly point to technological innovation, renewable energy, and financial development as the possible best practice of controlling China's emissions. Therefore, it is imperative for China's authorities to look more into energy transition (from fossil fuels to more sustainable energy sources). Financial development through internal policies that are geared towards liberalizing the financial sector is advised. This policy will aid in making funds available for capital projects such as sponsoring research and development which enhance innovation. This policy will cut across the energy sectors through the availability of funds for technological advancement of the sectors. The policy will also assist in making capital available to both the public and private parties who are interested in investing in renewable energy sector. It will lead to expansion and sustainability of the renewable energy sector in China. Also, the authorities should frame liberalization cum privatization policies that will attract both private and public parties into investing in the renewable energy sector. Also, as remarked, government or policymakers should pursue the policies to maintain the environmental quality by imposing more carbon taxes on production and support the sectors to transform their traditional high CO_2 emitter technologies into environmentally friendly technologies to sustain the environmental quality.

Conclusively, this study has implication for the other countries in the same economic and environmental performance category as China, and relevance to other emerging economies especially, from the Asian and African regions. The limitation of the study is based on the choice of the authors to limit the study to just China. A panel version of this study is encouraged, especially for the Asia countries. However, the topic is still open for more studies, especially with other relevant instruments and updated approaches.

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Author contribution The paper is written by the four authors named on the title page. Hence, Edmund Ntom Udemba conceived the idea and wrote the abstract with discussion and conclusion, Firat Emir wrote the methodology and estimation, Nazakat-Ullah Khan wrote the introduction, and Sadam Hussain wrote the literature review.

Availability of data and materials Data sources are outlined above in Table 1 and will be made available on demand.

Declarations

Ethics approval and consent to participate We, the authors, are giving our ethical approval and consent for this paper to be published in your journal if found publishable.

Consent to participate We, the authors, are giving our consent for participation in this paper to be published in your journal if found publishable.

Consent for publication We, the authors, are giving our consent for this paper to be published in your journal if found publishable.

Competing interests The authors declare no competing interests.

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