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# Dynamic and casual association between green investment, clean energy and environmental sustainability using advance quantile A.R.D.L. framework

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## ABSTRACT

This study examines the dynamic and causal relationship between green investment (G.I.), clean energy (C.E.), economic growth, and environmental sustainability with the help of an innovative approach named as quantile autoregressive distributed lagged (Q.A.R.D.L.) model using quarterly data from Q1-1995 to Q4-2019 for China. Our preliminary findings confirm data non-normality and structural breaks in all data series. Therefore, we have applied Q.A.R.D.L. that efficiently deals with these issues. We have further applied the Granger-causality in quantiles to check the causal association among the variables of interest. The findings through Q.A.R.D.L. estimation confirm that the error correction parameter is statistically significant with expected negative sign across major quantiles. In the long run, the results confirm that both C.E., and G.I. are significant mitigants of environmental pollution, however their emissions mitigating effects varies across lower, middle, and higher emissions quantiles. Furthermore, the findings through Granger-causality test confirm the existence of two-way causality between G.I., C.E., and carbon emissions across all quantiles. These results offer valuable policy implications.

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## 1. Introduction

The increasing environmental problems remain the hot topic and has been a critical research area for decades. The rapid increase in the centralisation of greenhouse gas (G.H.G.) emissions is a universal concern and posturing the exclusive challenges to the life of earth. It is apparent that human-based activities are the core reasons for an increase in the level of heat deceiving gases. This increasing level of G.H.G. releases tends to surge the level of global temperature by 1.8 Fahrenheit since 1880s, sea level by 177 mm during the past 10 decades, and carbon emissions to the 415 parts per billion in the atmospheres, respectively (Haile et al., 2020). However, if these patterns

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are continuous to rise, it will not only worsen the environmental quality but will also impose pressures on the future generations in the form of droughts and water scarcity, etc. In order to deal with these environmental challenges, governments and various other stakeholders have started to search an appropriate way to deal with these environmental issues (Amen et al., 2021; Baloch et al., 2021; Chien, Kamran, Albashar et al., 2021; Chien, Kamran, Nawaz, et al., 2021). Thus, a global discussion for the sustained economic path has been started.

In 1972, a United Nation (U.N.) conference on the '*human environment*' was held in Scotland, where the concept of '*sustainable economic development*' was appeared. After this conference, there is a remarkable increase in the universal responsiveness of environmental issues. In 1980, a world conservation strategy was organised by the '*the International Union for the Conservation of Nature and Natural Resources (I.U.C.N.)*', with the goal of attaining sustainable economic path through the preservation of natural resources. Furthermore, during June 1992, '*United nation conference on environment and development (U.N.C.E.D.)*' was organised by the U.N. The conference was arranged in '*Rio de Janeiro*' where almost 173 governments had participated and promised for the '*climate change conservation and environmental protection*'. In addition, during in 2016, 196 parties signed a '*Paris agreement*' in which all countries agreed to mitigate the level of G.H.G. emissions up to a certain level. This agreement becomes a momentous turning point for the global climate change action (UNFCCC, 2016). In this regard, China, being amongst one of the highest pollutant nation, also signed this partial agreement and now, its government is playing an important role in the reduction of carbon emissions. More specifically, China has assured to reduce the pattern of carbon emissions by almost 40–50% by the end of 2030.

In addition, development in the production and consumption of C.E. sources is one of the most prominent solutions to promote the environmental sustainability in China. Many other nations are also targeting the production of energy through cleaner sources to reduce the level of G.H.G. emissions. Various researchers regarded C.E. as an environmentally friendly source of energy, which not only reduces the level of carbon emissions, but also decouple the economic growth from negative externalities (Shah et al., 2020; Tahir et al., 2021; Xu & Buyya, 2020). Researchers indicated that the dependency on the C.E. limits the level of toxic releases which usually arise due to the dependency on coal, oil, and other gases (Anwar et al., 2021). In this regard, the use of C.E. sources tends to have a significant role in environmental protection. For instance, shift from unclean energy sources to C.E. sources can decrease half of the emissions. The present study, hence, regarded C.E. as a crucial factor to promote the environmental sustainability in China. The five-year plan of China (F.Y.P.; 2016–2020) underlines the premeditated importance of developing C.E. as a part of nation's energy supply. This plan provides overall guidance to achieve 15% share in the energy supply besides fossil fuel by the end of 2020, and 20% share by the end of 2030 (F.Y.P.; 2016–2020). During 2015, the total supply of energy through cleaner sources has reached around 0.453 billion tons of regular coal equivalent, which reports for 12% of the total primary energy supply. These developments in the sector of C.E. help nation to reduce the level of carbon emissions to the targeted level.



**Figure 1.** Trend of G.I. in China.

Source: The authors.

In addition to this, increase in the green investments (G.I.s) also help to promote the environmental sustainability. In China, G.I.s play dual role, for example, it activates and conduits the money into a 'low-carbon' economic transactions and on the other hand, it helps to promote the energy efficiency technologies and renewable energy projects as well (Sachs et al., 2019). Such efforts are positively contributing to the environmental quality (Wang & Zhi, 2016). This is so because G.I.s are exclusively used to finance environmental-responsive or eco-friendly projects which in turn tends to reduce the level of G.H.G. or carbon emissions. China is also emphasizing to promote the investment in environmentally friendly projects. For instance, since the F.Y.P.; 2016–2020, Chinese government has occupied the control in contracting the environmental governance. A lot of direct government investment has been made on the 'public infrastructure' to promote energy savings techniques to reduce the stress on the environment (Liu et al., 2020). Meanwhile, private organisations in China are also investing money in environmentally friendly and anti-pollutant projects, and hence, it has enlisted among one of those nations who are promoting G.I.s to improve the environmental conditions. The trend of G.I.s in China is shown in Figure 1. Some researchers have admired China as a 'green entrepreneurial state' due to its perilous efforts to promote the G.I. (Zhou et al., 2020).

More specifically, the trends in Figure 1 for G.I. over the last couple of decades is showing an upward shift which is no doubt a significant achievement towards sustainable practices as followed by Chinese economy. This is due to the fact that government has taken some significant steps to promote those investment projects having their minimum or no environmental impact in order to achieve sustainable solution. Hence, after analysing the current environment situations, present study believes that it is crucial to test the role of G.I. and C.E. in the CO<sub>2</sub> emissions of China.

In addition, it is believed that the essence of green economy is based on the sustainable development practices. For this turn, environmental protection is very important with the help of guiding the traditional industrial society to consider and

realise the energy revolution in the field of production, consumption, and circulation of goods. This would provide a good direction towards changing the pattern and level of linkage between energy consumption from traditional sources to renewable ones, higher level of emissions and pollutions to lower levels, and focusing more on those projects like G.I.s having their role as a panacea towards environmental degradation (He et al., 2019). However, for the transformation of green economy, one of the key points is to work simultaneous for the renewable energy as well as G.I. under the shadow of sustainable economic growth. However, as per the findings of United Nations Environment Programme (U.N.E.P.), one of the significant challenge is to promote the green transformation in the economy. For China, this challenge is under consideration through government-centred financing model for the promotion of renewable energy industry, however, the direct financing channels are not yet developed, where the green credit is accepted as the main channel for the green project financing along with the main force to develop green financial system (He et al., 2019). In this regard, examining the association between renewable energy and G.I. is of great practical significance from the context of China.

After reviewing the available literature, present study argues that there exist following research gaps in the existing debate of G.I., C.E., and CO<sub>2</sub>. First, the study found that the relationship between C.E. and CO<sub>2</sub> is well documented in the available literature, but to the best of our knowledge, the findings of the previous researchers do not reach at a definite solution. For instance, some researchers revealed the negative relationship between C.E. and CO<sub>2</sub> (Bilan et al., 2019; Sharif, Baris-Tuzemen et al., 2020), while other depicted the positive affiliation between CE and CO<sub>2</sub> (Çıtak et al., 2020; Shah et al., 2020). However, some researchers concluded the insignificant contributions of C.E. in CO<sub>2</sub> (Mehdizadeh Rayeni et al., 2021). Second, researchers believed that G.I. has a favourable effects on the environmental conditions of the nation. However, to the best of our knowledge, the empirical studies on the nexus between G.I.–CO<sub>2</sub> are rarely reported in the literate. Third, to the best of our knowledge, the collective impact of C.E. and G.I. has not been investigated by the prior researchers, specifically for the case of China. Hence, present study contributes to the existing literature in following ways. First, the study examines the collective impact of G.I. and C.E. on CO<sub>2</sub> for the case of different provinces of China. Second, unlike the previous studies, present study will use Q.A.R.D.L., an advanced econometric technique to capture the more prominent influence of G.I. and C.E. on CO<sub>2</sub>.

Meanwhile, based on the study motivation, various contributions as also associated to it. For instance, this study has provided a good justification for exploring the long- as well the short-run association between the variables of interest while covering some significant points under literature gap. This was the very first motivation after reviewing both theoretical and empirical literature till date. The second motivation to contribute to the existing literature is based on the novel approach named as Q.A.R.D.L. while investigating the association between the variables over range of quantiles which is a major contribution in the econometric literature. It is observed that existing literature is mainly considering the traditional methods like O.L.S. or similar other techniques to explore the relationship between the variables, whereas the implication of Q.A.R.D.L. is very limited. Meanwhile, as compared to linear

A.R.D.L. method of estimation, Q.A.R.D.L. has a significant advantage of introducing possible asymmetries under different ranges of the quantiles. It is also believed that Q.A.R.D.L. approach is more superior comparatively to other linear models in three different ways. Firstly, it allows to explore the locational asymmetry within its conditional distribution. Secondly, it helps to address long-term and short-term association between the variables simultaneously. Thirdly, this model also allows the cointegrating coefficient to vary over the innovation quantile, as caused by shocks. Furthermore, the implication of Q.A.R.D.L. helps to deal with both long- and short-run estimation which is no doubt a significant contribution till date. Thirdly, the findings under present study through Q.A.R.D.L. confirms that G.I. and C.E. are good indication towards reducing the environmental degradation in the economy of China, hence providing a sustainable solution for the decision makers. Fourthly, the direct and destructive role of economic growth in terms of G.D.P. towards environmental pollution confirm that growth in China is not under sustainable practices, hence highlighting a major issue for the policymakers to consider.

Remaining study is based on the following structure: section 2 evaluates the existing debated on G.I., C.E., and CO<sub>2</sub>, the theoretical grounds as well as the construction of hypothesis. Section 3 presents the econometric methods of the study along with data collection process and variables explanation. Section 4 highlights the findings along with hypothesis testing. The last section concludes the study along with significant policy recommendation to solve the global environmental issues. The study also offers some directions for the upcoming researchers in the last section.

## 2. Literature review

This section presents the empirical review on the existing relationships among the variables of interest along with the development of hypotheses. The theoretical support of the study is also documented in this section. As the role of renewable energy is very constructive towards the environmental issues, therefore, present study considers C.E. as an equivalent to renewable energy. A number of researchers have indicated the crucial role of C.E. in reducing the level of CO<sub>2</sub>. In this regard, the nexus between C.E.–CO<sub>2</sub> remains the highly debatable topic among the researchers. For instance, Asongu et al. (2019) conducted their research on 40 African economies with the aim to scrutinise the role of C.E. in CO<sub>2</sub>. Results of the study indicated the negative relationship between C.E. and CO<sub>2</sub>. During the same decade, Zhang et al. (2017) tested the empirical association between C.E. and CO<sub>2</sub> and reported the negative relationship between these variables for the period of 1970–2012. Jebli et al. (2019) tested the dynamic relation between C.E., tourism, G.D.P., and CO<sub>2</sub> emission for the case of 22 central and south American economies. Results of the study exhibited that C.E. is negatively, while tourism and G.D.P. are positively related with the level of CO<sub>2</sub>. Bilan et al. (2019) conducted a research on the E.U. member states while claiming that C.E. is a significant predictor of environmental sustainability. Khan et al. (2020) also indicated the positive relationship between C.E. and CO<sub>2</sub> emissions. The study suggested that there is a need to promote the production of energy through the cleaner sources in order sustain environmental sustainability.

In addition, Shahzad, Qu, Javed et al. (2020) have also considered the title of environmental sustainability from the context of manufacturing industry in Pakistan. It is stated that environmentally sustainable development is among those significant strategies having their green output. Shahzad et al. (2021) have also provided a good addition from the context of sustainable development practices while focusing on large and medium size enterprises. Razzaq, Sharif, Najmi et al. (2021) have taken into account the economy of the U.S.A. for analysing the trends in environmental quality and economic development. It is found that there is a unidirectional causality between carbon emission, energy efficiency and economic growth as well. Razzaq, Wang, et al. (2021) covers the B.R.I.C.S. economies for examining trends in consumption-based carbon emission through green technology innovation. It is observed that green innovation plays a significant role in mitigating the carbon emission in B.R.I.C.S. economies. In addition, there are some other studies having their meaningful contribution while exploring the trends sustainable development practices under different regional contexts (Baloch et al., 2021; Razzaq, Sharif, Ahmad et al., 2021; Shahzad, Qu, Zafar et al., 2020; Usman et al., 2021).

Iorember et al. (2020) tested the association between C.E. and the environmental degradation for the Nigerian economy using the A.R.D.L., and Granger Causality (G.C.) tests during 1990–2016. The study concluded that the consumption of renewable energy enhances the quality of the Nigerian ecosystem while the financial growth deteriorates it. Sharif, Mishra et al. (2020) explore the linkage between C.E. and CO<sub>2</sub> for the case of Top-10 polluted nations during the period of 1990–2017. In this regard, the study applied A.R.D.L. and confirms a direct relationship between the stated variables in case of Japan, South Korea, U.S.A., Germany, China, and Brazil. Kirikkaleli & Adebayo (2021) tested the empirical connection between C.E., financial development and CO<sub>2</sub>. Results of the study exhibit a negative linkage between C.E., carbon emission and financial development, respectively. Zeb et al. (2014) also indicate a negative relationship between C.E. and CO<sub>2</sub>. The study concluded that when economies are concerned about the deteriorating effects of climate change, the consumption and production of C.E. would help to promote the environmental sustainability by reducing the level of CO<sub>2</sub> and other toxic gases. Ahmed et al. (2021) state that the production and consumption of energy through cleaner sources will not only help to mitigate the adverse climate change effects, but also provides the way to achieve sustainable economic growth.

However, the debate on C.E.–CO<sub>2</sub> relation is still an ongoing phenomenon. Contrast to the findings of above studies, some researchers come to the field by showing the negative affiliation between C.E. and CO<sub>2</sub>. For instance, Shah et al. (2020) directed their research on D-8 economies with the intent to investigate the role of institutional stability, economic growth, and renewable and non-renewable energy on the environmental deterioration. The study applied F.M.O.L.S. and D.O.L.S. methods to estimate the empirical findings. The results of the study exhibit a negative connection between institutional stability and environmental deterioration, while positive affiliation between economic growth, renewable and non-renewable energy and environmental deterioration have been found. Sharif, Mishra et al. (2020) investigated the empirical association between C.E. and CO<sub>2</sub>. For the case of top 10

most polluting states, the study concludes a substantial negative relationship between renewable energy and environmental deterioration in China, Canada, South Korea, Japan, Brazil and the U.S.A. In contrast, in Indonesia, India and Russia, the results were quite opposite. Çıtak et al. (2020) also indicated the negative relationship between CE and CO<sub>2</sub>. Mehdizadeh Rayeni et al. (2021) tested the non-linear relationship between CE and CO<sub>2</sub>. For this purpose, the study analyses the data of G7 economies for the period of 1985–2018 and applied NARDL approach to capture the asymmetries among the chosen variables. Results of the study indicate a positive shock in C.E. but insignificantly contributes to the CO<sub>2</sub>, while a negative shock in C.E. tends to increase the level of CO<sub>2</sub>. Nathaniel and Khan (2020) investigated the impact of renewable and non-renewable sources of energy consumption along with economic growth, urbanisation, and financial development on the degradation of the environment. They have applied a technique of AMG for the Middle East and North Africa (M.E.N.A.) states for the period of 2002 to 2016. The results infer that financial growth, urbanisation, and economic growth all deteriorate the ecosystem of the selected countries. It further concludes that renewable energy sources do not have a significant impact on environmental quality. However, non-renewable sources impose a significant effect on environmental deterioration. Hence the study suggested to encourage and boost the consumption of clean energies to mitigate the decline of their ecosystem.

Summing up the above literature, present study argues that although, the studies on the nexus between C.E.–CO<sub>2</sub> are well documented in the existing literature. However, the findings do not reach at the definite solution, hence, there is a room to re-conduct the study on the nexus between C.E. and CO<sub>2</sub> by using advanced econometric techniques. However, after reviewing the above literature, present study postulates that:

H1: ‘There is a significant relationship between C.E. and carbon emissions’

There is no doubt that pollution is a threat to environment. The higher the pollution, the worsen the environmental conditions. Researchers indicated that pollution is a result of inadequacies in the process of production (Porter & Van der Linde, 1995). Hence, it is suggested that there is a need to promote such investments which stimulates the efficient production process. Such investments which intensify the overall efficiency in the process of production are referred to as G.I.s. G.I.s are not only confined to the efficient production process, but also helps to promote the environmental sustainability via water hygiene and waste dispensation and reprocessing. (Khan et al., 2021). However, the literature availability on the relationship between G.I. and CO<sub>2</sub> is not extensive. For example, Li et al. (2021) conducted a study on China with the aim to answer, ‘how good is G.I. for the environmental conditions’. After analysing the data for the period of 1995–2017, the study inducted the significant role of G.I. in reducing the level of G.H.G. emissions.

Zahan and Chuanmin (2021) also conducted their research on China with the intend to explore the contributions of G.I. in C.E. and CO<sub>2</sub>. Findings of the study unveiled the positive role of G.I. in C.E., while the negative role of G.I. in CO<sub>2</sub>. Meo and Abd Karim (2021) tested the role of G.I.s and green bonds in the reduction of carbon emissions. In this regard, the study gathered the data from top 10 advanced



economies for the period of 2008–2019. Results of the study exhibited the positive role of G.I.s and bonds in the reduction of carbon emissions. Similarly, Sachs et al. (2019) also highlighted the positive role of G.I. in improving the environment quality. The study argued that the investment in environmentally friendly projects is crucial to improve the environmental conditions. Shen et al. (2021) tested the influence of G.I., financial development, and energy consumption in the reduction of CO<sub>2</sub>. For this purpose, the study collected the data from China for the period of 1995–2017 and showed the significant contributions of G.I. and financial development in the reduction of carbon emissions. Sachs et al. (2019) emphasised to promote the green finance (i.e., G.I., green bond, and green funds) to promote the environmental sustainability. Results of the study exhibited a positive role of G.I. and projects in climate change mitigation. Thus, the study concluded the negative relationship between G.I. and CO<sub>2</sub>. Khalil and Nimmanunta (2021) narrated that G.I. is a blessing for a nation's environment it promotes the production and usage of clean energies and provides the means to evaluate the advance and environmentally friendly technologies which negatively influences the level of carbon emissions. Vasylyk (2021) indicated that G.I. provides the means to finance the sustainable projects which protect the environment from the effects of climate change. Al-Kaabi and Nobanee (2020) conducted a mini review and demonstrated that G.I. helps to promote environmentally friendly projects, which is very advantageous for the environmental quality of a country.

Triangulating the above discussion, GI is very favourable to promote the environmental sustainability. However, only a few researchers have tested the role of G.I. on CO<sub>2</sub> and there is a need to re-investigate this relationship not only by incorporating some additional variables but also through some advance econometric techniques to get more pronounce results. Hence, it is hypothesised that:

H2: 'There is a significant relationship between G.I. and carbon emissions'

The relationship between the variables of interest is justified under the theoretical lenses of environmental Kuznets curve (E.K.C.), which is normally categorises into three phases: 'i.e., pre-industrialisation phase, industrialisation phase, and post industrialisation phase'. First two phases referred as 'primitive phases of development'. During the primitive phases, the capital investments are prepared to accelerate the rate of industrialisation. These investments integrally activate the production of national output, without compensating the growth driven ecological adversities. However, during the phase of post industrialisation, there is a propensity to initiate eco-friendly investments (generally referred as G.I.), that can be interpreted in the terms of technique effect (Musibau et al., 2021). In line with this notion, Shen et al. (2021) observed that G.I. is the efficient way to deal with the climate change issues, as these investments do not only mitigate the environmental issues, but also provide the means to invest in renewable projects, which is, again, having favourable effects on the environmental conditions of a nation. Hence, present study uses E.K.C. as a baseline theory to justify the empirical linkage among modelled variables. Furthermore, there are some other studies having their significant attention towards the issue of environmental and climate changes (Chien, Anwar et al., 2021; Razzaq, Sharif, Ahmad, et al., 2021; Razzaq, Sharif, Najmi, et al., 2021; Sun et al., 2021).

### 3. Research methodology

This research aims to examine the non-linear association between G.I., C.E., economic growth, and carbon emission in China with the help of an innovative approach named as quantile autoregressive distributed lagged or Q.A.R.D.L. during the study period of Q1-1995 to Q4-2019. This method was suggested by Cho et al. (2015) in order to explore the dynamic and non-linear linkage between variables of interest. Furthermore, one of the core rationale to apply QARDL is that it helps to examine how under three ranges of quantiles (low, medium, and high), the association between independent and dependent variable exists. As stated earlier, traditional methods like O.L.S. estimation are lacking with such advantages for exploring the relationship over range of quantiles. Furthermore, the key motives for using Q.A.R.D.L. estimation for generating empirical outcomes is that it helps to examine the heterogenous impact of selected independent variables from lower order quantiles to higher order quantiles. This would help to justify the significance of time varying change in the carbon emission as determined by G.I., C.E., economic growth, and square of economic growth, respectively.

More specifically, the dependability of the parameters under each quantile is further examined with the help of the Wald test for both long- and short-run estimation. However, in its traditional terms, the linear A.R.D.L. model can be developed with the help of following Equation 1, below:

$$\begin{aligned} CO_2 = & \alpha + \sum_i^p \beta_1 CO_{2t-i} + \sum_i^q \beta_2 GI_{t-i} + \sum_i^m \beta_3 CE_{t-i} + \sum_i^n \beta_4 GDP_{t-i} \\ & + \sum_i^r \beta_5 GDP_{2t-i} + \epsilon_t \end{aligned} \quad (1)$$

In the above Equation 1, the term like  $\epsilon_t$  showing the white noise error terms as shown with the help of lowest field with the created with the help of  $CO_2$ ,  $GI_t$ ,  $CE_t$ ,  $GDP_t$ ,  $GDP_{2t-1}$ ,  $Y_{t-1}$ . In addition, the symbols like p, q, m are showing the lag orders which are based on the Schwarz Info Criterion (S.I.C.). Meanwhile, the titles like  $CO_2$ , G.I., C.E., G.D.P., and G.D.P.2 shows the natural log of the carbon emission, G.I., C.E., gross domestic product, and square of gross domestic product over the study period. However, the revision of Equation 1 into quantile form can provided the following Equation 2.

$$\begin{aligned} Q_{CO_2} = & \alpha(\tau) + \sum_i^p \beta_1(\tau) CO_{2t-i} + \sum_i^q \beta_2(\tau) GI_{t-i} + \sum_i^m \beta_3(\tau) CE_{t-i} \\ & + \sum_i^n \beta_4(\tau) GDP_{t-i} + \sum_i^r \beta_5(\tau) GDP_{2t-i} + \epsilon_t(\tau) \end{aligned} \quad (2)$$

Meanwhile, in Equation 2, the term like  $\epsilon_t(\tau) = CO_{2t} - Q_{CO_2}(\tau/\epsilon_{t-1})$  and  $0 < \tau < 1$  are added to reflect the quantiles. However, in order to apply the data analysis methods, various pairs of quantiles are considered ranging from 0.05<sup>th</sup> to 0.95<sup>th</sup>, respectively. Additionally, the probability of the sequential correlation in the white noise error is reflected with the help of Equation 3.

$$\begin{aligned}
Q_{\Delta CO_2_t} = & \alpha(\tau) + \rho CO_{2_{t-i}} + \varphi_1 GI_{t-i} + \varphi_2 CE_{t-i} + \varphi_3 GDP_{t-i} + \varphi_4 GDP2_{t-i} \\
& + \sum_{i=1}^p \beta_1(\tau) CO_{2_{t-i}} + \sum_{i=1}^q \beta_2(\tau) GI_{t-i} + \sum_{i=1}^m \beta_3(\tau) CE_{t-i} \\
& + \sum_{i=1}^n \beta_4(\tau) GDP_{t-i} + \sum_{i=1}^r \beta_5(\tau) GDP2_{t-i} + \epsilon_t(\tau)
\end{aligned} \tag{3}$$

In addition, Equation 3 can also be reflected with the help of error correction model while taking into account quantile ARDL approach with the help of Equation 4.

$$\begin{aligned}
Q_{\Delta CO_2_t} = & \alpha(\tau) \\
& + \rho(\tau)(CO_{2_{t-i}} - \omega_1(\tau)GI_{t-i} - \omega_2(\tau)CE_{t-i} - \omega_3(\tau)GDP_{t-i} - \omega_4(\tau)GDP2_{t-i}) \\
& + \sum_{i=1}^{p-1} \beta_1(\tau)\Delta CO_{2_{t-i}} + \sum_{i=0}^{q-1} \beta_2(\tau)\Delta GI_{t-i} + \sum_{i=0}^{m-1} \beta_3(\tau)\Delta CE_{t-i} \\
& + \sum_{i=0}^{n-1} \beta_4(\tau)\Delta GDP_{t-i} + \sum_{i=0}^{r-1} \beta_5(\tau)\Delta GDP2_{t-i} + \epsilon_t(\tau)
\end{aligned} \tag{4}$$

After analysing the long-run association between variables of interest, next step is to examine the short-run impact of past values of carbon emission on the current values of  $CO_2$  with the help of  $\beta_* = \sum_{i=1}^{p-1} \beta_1$ . At the same time, past and collective short-run effect of Y on the current values is explored with the help of  $\beta_* = \sum_{i=1}^{q-1} \beta_2$ . A similar process is followed for examining the past and lagged values of C.E., G.I., economic growth, and square of economic growth on current and lagged values of carbon emission.

After Q.A.R.D.L. estimation, the Wald test has been applied to examine the long-short term asymmetric influence of G.I., C.E., economic growth, and square of economic growth on carbon emission. Additionally, Granger-causality between the variables is also tested with the help of Granger (1969) test as shown under analysis part of the study. However, to consider the study quantiles Troster (2018) has provided a good suggestion for applying the Granger-causality among the variables under different quantiles and similar is applied in this study.

#### 4. Results and discussion

Descriptive results are provided in Table 1 with range of statistics. It is observed that mean trend for the study variable like G.D.P.2 is the highest, followed by G.D.P., CE,  $CO_2$ , and GI. This would specify that economic growth in China is more than the carbon emission, G.I. and C.E., respectively. On the other side, the median trend for all of the study variables is also following the mean approach where highest score is linked with the G.D.P.2. More specifically, it is found that maximum data point for the G.D.P.2 is 8.22 and for G.D.P., it is 4.034, respectively. Meanwhile, both kurtosis and skewness have also demonstrated the positive trends for all of the study variables. Finally, Table 1 reports the output for the Jarque-Bera test statistics along with the relative probability values as well. Under J-B tests, the null hypothesis specifies that data is normally distributed whereas alternative supports that it is not. As per the findings, it is found that the J-B values for the study variables like carbon emission,

**Table 1.** Descriptive statistics.

Description	CO <sub>2</sub>	GI	CE	GDP	GDP <sup>2</sup>
Mean	1.257	1.005	1.469	3.539	7.235
Median	1.222	1.006	1.447	3.524	7.204
Maximum	1.532	1.284	1.706	4.034	8.225
Minimum	0.865	0.688	1.231	2.988	6.135
Std. Dev.	0.428	0.248	0.344	0.447	1.052
Skewness	0.319	-0.216	0.157	0.069	0.358
Kurtosis	1.933	4.073	1.421	1.883	2.172
Jarque-Bera	8.523	6.817	15.430	7.745	8.033
Probability	0.000	0.000	0.000	0.000	0.000

CO<sub>2</sub> = Carbon emission M.T. per capita, GI = Green Investment converted from million yuan to Millions U.S.D. using real exchange rate, CE = Clean energy represented by the consumption of renewable energy, G.D.P. gross domestic product (constant U.S.D.. CO<sub>2</sub> emission is measured in terms of metric tons per capita, GI investment measures in U.S.D., clean energy measures in terms of total investment in such projects observed through U.S.D., G.D.P. measures in current U.S.D.. All the values are converted into natural logarithm.

Source: The authors.

G.I., C.E., economic growth in terms of G.D.P., and square of G.D.P. have shown significant scores at 1%. This would justify the argument that H1 is accepted which claims that data for the study variables is not normally distributed. Therefore, this study is going to explore the non-linear association between CO<sub>2</sub>, G.I., C.E., G.D.P., and G.D.P.<sup>2</sup> during the period of interest with the help of quantile A.R.D.L. approach.

The findings for the unit root test are presented in Table 2 where A.D.F. and Z.A. tests were applied. It is observed at A.D.F. (level) the study variables are found to be statistically insignificant. On the other side, the findings for A.D.F. ( $\Delta$ ) specifies the argument that carbon emission, G.I., C.E., and G.D.P. are found to be negatively significant at 1%. This would justify the argument that all of these variables are showing their significant output at first difference, therefore they are observed as stationary at first difference when examined with the help of A.D.F. ( $\Delta$ ). Furthermore, the results in Table 2 confirms that findings for Z.A. at level are also found to be insignificant, except for CO<sub>2</sub>. However, when Z.A. ( $\Delta$ ) have been observed, results are found to be negatively significant at 1%, hence providing the evidence that variables of interest are stationary too at first difference with the help of the Z.A. test.

Table 3 reports the output for the quantile A.R.D.L. estimation both under long- and short-run with the help of coefficients at different levels of quantiles ranging from lower to higher level, respectively. The findings under long-run estimation show that the estimated speed of adjustment coefficient of  $p^*$  is found to be significant and negative. More specifically, the values of  $p^*$  are significant from medium order quantiles (0.50th) to higher order quantiles, except for 0.95th as shown in Table 3. This result has confirmed the fact that presence of reversion to long-run equilibrium among the study variables like carbon emission, G.I., C.E., G.D.P. and square of G.D.P., respectively.

In addition, the findings in Table 3 show that there is a significant and negative impact of G.I. on CO<sub>2</sub> emission in the economy of China during the study period. However, this impact of G.I. on C.O. is heterogenous in nature and found to be negatively significant from 0.05th quantile to 0.70th quantile. More specifically, it is observed that the estimated impact of G.I. on C.O. is higher for the lower order quantiles and lower for the medium order quantiles. However, the highest negative

**Table 2.** Unit root test.

Variable	CO <sub>2</sub>	GI	CE	GDP
ADF (Level)	-0.120	-1.795	-1.752	-2.513
ADF ( $\Delta$ )	-3.620***	-3.432***	-3.728***	-4.526***
ZA (Level)	-3.420**	-1.502	-0.958	-1.317
Year	2007Q4	2015Q1	2011Q2	2008Q1
ZA ( $\Delta$ )	-3.985***	-4.965***	-5.526**	-5.248***
Year	2007 Q3	2010Q4	2007Q1	2011Q2

CO<sub>2</sub> = Carbon emission M.T. per capita, G.I. = Green Investment converted from million yuan to Millions U.S.D. using real exchange rate, C.E. = Clean energy represented by the consumption of renewable energy, G.D.P. gross domestic product (constant U.S.D.). \*\*\*, \*\* and \* indicate significance at the 1%, 5% and 10% levels, respectively.

Source: The authors.

**Table 3.** Quantile estimation results.

Quantiles	Constant		Long-Run results				Short-run Results				
	$\alpha$	$\rho$	$\beta_{GI}$	$\beta_{CE}$	$\beta_{GDP}$	$\beta_{GDP^2}$	$\phi_1$ (CO2)	$\omega_0$ (GI)	$\lambda_0$ (CE)	$\theta_0$ (GDP)	$\delta_0$ (GDP <sup>2</sup> )
0.05	2.519**	-0.161	-0.662**	-0.035*	0.492**	-0.232	0.436***	-0.085	0.095	0.060	-0.145
0.10	0.195	-0.218	-0.836**	-0.177*	1.294**	-0.15	0.430***	0.0940	0.096	0.151	-0.226
0.20	0.907*	-0.21	-0.982**	-0.474	2.764**	-0.048	0.381***	0.054	0.010	0.274*	-0.226
0.30	0.891*	-0.216	-0.289***	-0.532	3.634**	-0.044	0.365***	0.030	0.022	0.184**	-0.224
0.40	0.956**	-0.213	-0.398*	-0.335**	2.204**	-0.191	0.341***	0.039	0.034	0.309**	-0.202
0.50	0.803**	-0.213**	-0.417***	-0.332**	1.612**	-0.297	0.425***	-0.0414*	0.047	0.376**	-0.173
0.60	0.523	-0.203**	-1.441***	-0.103*	1.425**	-0.356***	0.401***	-0.098**	0.080**	0.318**	-0.150
0.70	0.382	-0.187**	-1.551*	-0.160**	1.425**	-0.259***	0.436***	-0.0875*	-0.083**	0.260*	-0.153
0.80	0.372	-0.198**	-1.655	-0.139**	1.512*	-0.217**	0.449***	-0.163***	-0.063**	0.261*	-0.291
0.90	1.503**	-0.131**	-1.748	-0.132**	1.396*	-0.305***	0.443***	-0.176***	-0.065**	0.104	-0.265
0.95	1.57*	-0.062	-0.988	-0.273	1.517	-0.562**	0.461***	-0.122**	-0.059**	0.060	-0.145

Note: The table reports the quantile estimation results. The standard errors and t values are not report for the sake of brevity. \*\*\*, \*\* and \* indicate significance at the 1%, 5% and 10% levels, respectively. CO<sub>2</sub> = Carbon emission M.T. per capita, G.I. = Green Investment converted from million yuan to Millions U.S.D. using real exchange rate, C.E. = Clean energy represented by the consumption of renewable energy, G.D.P. gross domestic product (constant U.S.D.).

Source: The authors.

impact is -1.55 as observed under 0.70th quantile of the study. These results justify the fact that higher G.I. is leading towards the reduction of CO<sub>2</sub> in the economy of China, hence demonstrating its significant position towards the improvement of environmental quality. As shown under study background, there is an increasing trend in the G.I. In China since 1980s to date which indeed a good indication towards the reduction of environmental degradation. In this regard, research findings as shared by L. Wang et al. (2020) have investigated the trends in sustainable development of China. It is stated that G.I. is a good sign in controlling the carbon emission. Therefore, it is contributing towards the achievement of sustainable growth. Shen et al. (2021) have also examined the role of G.I. towards reducing the carbon emission with the help of panel analysis in China during 1995–2017. The study findings confirm that G.I. is very much supportive while controlling the negative environmental outcomes in the form of higher carbon emission. Furthermore, research work as contributed by Huang et al. (2020) have examined the linkage between G.I. and carbon emission and suggested that firms should invest in those projects which are based on efficient green technology in order to protect the natural environment. Afni et al. (2018) also provide their contribution while claiming that G.I. is a good indication towards carbon emission and its disclosure as well. Based on the above findings, H2 is supported which claims that there is a significant relationship between G.I. and carbon emissions (An et al., 2021; Razaq, Ajaz et al. (2021).

In addition, [Table 3](#) reports the association between C.E. and carbon emission over all three ranges of quantiles. It is found that C.E. is negatively and significant linked with the carbon emission in the economy of China where highly significant relationship is found from medium order to higher order quantiles except for 0.95th. This would state that higher level of C.E. in the region of China is a positive indication towards controlling the environmental degradation like carbon emission. More specifically, C.E. refers to all those projects of energy having their minimum or no environmental impacts. In this regard, research contribution as [Usman et al. \(2020\)](#) have explored the dynamic relationship between C.E. and carbon emission for the economy of Pakistan. It is found that there existence asymmetry in the nexus between C.E. and carbon emission. It is further stated that country like Pakistan has a significant potential of C.E. which can reasonably improve the environmental quality in the coming time. [Murshed et al. \(2021\)](#) have focused on the economy of Bangladesh while exploring the dynamic relationship between C.E. transition and low-carbon economy during 1975–2016. Their findings confirm that C.E. transition within the economy of Bangladesh can be panacea towards national aggravating environmental issues. Based on the above findings H1 is also supported.

Finally, the findings under long-run estimation through quantile A.R.D.L. have shown that G.D.P. has its significant and positive indication towards higher level of environmental degradation like CO<sub>2</sub>. There is a common phenomenon that for the economic growth, the production and transportation of various goods and services are linked with the utilisation of various energy sources where the role of fossil fuel is inevitable. In this regard, higher economic growth means that more consumption of energy specifically those which are entitled as traditional and non-renewable sources, hence leading to more environmental hardships. In this regard, [Waheed et al. \(2019\)](#) have confirmed that economic growth is a significant source of carbon emission specifically in the highly developing economies. However, on the other side, there is no association between economic growth and carbon emission for the developed countries. [Q. Wang and Zhang \(2020\)](#) show their empirical evidence while claiming that economic activities are putting negative effect towards decoupling of natural environment in the form of carbon emission. [Zhang et al. \(2014\)](#) have examined the impact of economic growth in China on carbon emission during the period of 1978–2011. It is found that increase in the economic growth is significantly playing its role towards carbon dioxide emission intensity. More specifically, among economic growth, industrialisation, and industrial structure, the role of economic growth is observed as main influencer towards carbon emission intensity during the study period.

Finally, the findings under long-run estimation also provides the empirical outcomes for square of G.D.P. and its relationship with carbon emission. Comparatively to G.D.P., it is found that there is a negative and significant impact of G.D.P.<sup>2</sup> on CO<sub>2</sub>. However, this relationship is significant only from above medium order quantiles to higher order quantiles till 0.90th as shown in [Table 3](#). This means that G.D.P. square is causing its constructive role in reducing the carbon emission, hence improving the environmental quality in China. This would indicate that higher G.D.P. square is a good sign towards environmental sensitivity like CO<sub>2</sub>, therefore, some progressive role is found towards the natural environment of China. In this regard,

one of the recent contribution is provided by Malik et al. (2020) where the association between G.D.P. square and carbon emission is tested through some advanced econometric techniques. It is found that G.D.P. square is playing its productive role in reducing the carbon emission. Sharif, Baris-Tuzemen et al. (2020) have also examined the role of G.D.P. square towards ecological footprints for the economy of Turkey during 1965–2017. The study findings confirm that G.D.P. square is significantly and negatively linked with the ecological footprint.

In addition, the findings for the short-run estimation have also been presented in Table 3 where it is found that past and lagged values of CO<sub>2</sub> are found to be the direct source of current and lagged values of CO<sub>2</sub>. It means that recent changes in the CO<sub>2</sub> are also because of the CO<sub>2</sub> emission in the economy of China. Furthermore, past, and lagged scores of G.I. are also putting their significant pressure towards reducing the current and lagged values of CO<sub>2</sub> in China. This impact is observed from medium order quantiles to higher order quantiles, where the findings under 0.60th, 0.80th and 0.90th quantiles are highly significant as shown in Table 3. Furthermore, the past and lagged scores of C.E. are also accepted as a good indication for reducing the current and lagged values of CO<sub>2</sub>. Finally, it is observed that like long-run estimation, past and lagged scores of G.D.P. are leading towards more environmental pollution. However, square of G.D.P. is showing its insignificant results in terms of its past and lagged values in order to predict CO<sub>2</sub>.

The results in Table 4 are covering the output for the Wald test for the constancy of the parameters, where H<sub>0</sub> indicates that there is no parameter constancy of speed of adjustment parameters whereas H<sub>1</sub> indicates that it exists. The findings in Table 4 show that H<sub>0</sub> is rejected hence it is claimed that there exists parameter constancy of speed of adjustment parameters. Furthermore, for the long-run estimation, the findings through the Wald test also helps to accept H<sub>1</sub> which claims that the long-run parameters of the study variables like G.I., C.E., economic growth, and square of economic growth are dynamic in nature under different quantiles for the Chinese economy. Finally, the findings for the H<sub>0</sub> of the linearity of the short-run cumulative impact of past levels of G.I.N. under the Wald test estimation are also rejected.

Finally, Table 5 reports the output for the G.C. in the quantiles for the study variables. It is found that for the overall quantiles ranging from 0.05th to 0.95th, there exists a bidirectional causality between the variables among all model variables except carbon emissions to G.D.P., where one-way causality exists. Notably, the causality is equally stable across all quantiles.

## 5. Conclusion and policy implications

G.I. and C.E. are observed as good source in dealing with the environmental pollutions in different regions. However, at the same time, the role of economic growth is also observed as prone to sustainable environment due to higher emission in the nature. This study considers the economy of China for examining the role of G.I., C.E., and economic growth towards CO<sub>2</sub> emission. This study has applied quantile A.R.D.L. estimation approach suggested by Cho et al. (2015) as it is very much helpful to examine whether the variety of quantiles in terms of low, medium, and high

**Table 4.** Results of the Wald Test for the constancy of parameters.

Variables	Wald-Statistics [p-value]
Long-Run Parameters	
$\rho$	5.928*** [0.000]
$\beta_{GI}$	7.418*** [0.000]
$\beta_{CE}$	5.726*** [0.000]
$\beta_{GDP}$	8484*** [0.000]
$\beta_{GDP}^2$	3.728*** [0.000]
Short-run parameters	
$\varphi_1$	8.923*** [0.000]
$\omega_0$	2.652** [0.047]
$\lambda_0$	2.415* [0.071]
$\theta_0$	1.213 [0.326]
$\delta_0$	0.976 [0.792]

Null hypotheses: Parameters are constant,  $CO_2$  = Carbon emission M.T. per capita, G.I. = Green Investment converted from million yuan to Millions U.S.D. using real exchange rate, C.E. = Clean energy represented by the consumption of renewable energy, G.D.P. gross domestic product (constant U.S.D.).

Source: The authors.

**Table 5.** Test results of G.C. in quantile.

Quantiles	[0.05–0.95]	0.05	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	0.95
$\Delta GI_t$ to $CO_2_t$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$\Delta CO_2_t$ to $\Delta GI_t$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$\Delta CE_t$ to $CO_2_t$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$\Delta CO_2_t$ to $\Delta CE_t$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$\Delta GDP_t$ to $CO_2_t$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$\Delta CO_2_t$ to $\Delta GDP_t$	0.337	0.682	0.614	0.764	0.736	1.032	0.544	0.456	0.995	0.910	0.832	0.902
$\Delta GI_t$ to $CE_t$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$\Delta CE_t$ to $\Delta GI_t$	0.641	0.625	0.675	0.514	0.563	0.472	0.563	0.618	0.652	0.605	0.430	0.712

Null hypothesis: No Casual association exist,  $CO_2$  = Carbon emission M.T. per capita, G.I. = Green Investment converted from million yuan to Millions U.S.D. using real exchange rate, C.E. = Clean energy represented by the consumption of renewable energy, G.D.P. gross domestic product (constant U.S.D.).

Source: The authors.

ranges for the G.I., C.E., economic growth, and square of economic growth affect the carbon emission during the study period. Furthermore, this study also considers the causality in the quantiles with the help of Granger-causality test. The study findings through quantile A.R.D.L. estimation confirmed that the value of error correction parameter is statistically significant with the expected negative sign in the study quantiles. This would justify the presence of significant reversion to long term association between the G.I., C.E., economic growth, square of economic growth, and carbon emission in China. In particular, the study findings confirm that there is a significant and constructive role of G.I. and C.E. towards the reduction of  $CO_2$  in China under long-run estimation. This means that both of these factors are among the key role players towards providing some relief to natural environment. On the other side, economic growth is found to be a direct source for higher level of carbon emission where square of G.D.P. not. On the other side, short-run estimation show that past



and lagged values of G.I. and C.E. are something like positive indication for lower CO<sub>2</sub> whereas G.D.P. is leading to more environmental threats as well. This would justify the argument that quality of natural environment in China is prone towards deterioration at higher level of economic growth in terms of G.D.P., hence growth trajectory being achieved by China is not sustainable in nature. Among the various reasons, the consumption of more fossil fuel for the production and transportation of goods and services where higher carbon emission is observed. On the other hand, low penetration of some renewable energy sources is another reason for non-sustainable growth in China. Therefore, some strong policies, and governmental regulations are the need of time, so that negative environmental outcomes can be controlled in an appropriate way.

Considering the empirical outcomes, C.E. and G.I. are good source of lower environmental degradation. In this regard, government should promote more investment in green projects along with the C.E. utilisation so that more positive results can be generated in the upcoming time. Finally, this study has some limitations for which future directions can easily be extracted. For instance, this research is entirely focusing on Chinese economy whereas no attention is given to other A.S.E.A.N. members where the problem of higher environmental degradation also exists. Secondly, the investment trends towards C.E. have been taken in terms of aggregate way where there is a big gap to cover such trends regarding the individual components of C.E. like solar, thermal, and hydro energy as well. Thirdly, this study is missing with the consideration of environmental regulations like green taxes/environmental taxes while exploring their role towards environmental quality. Fourthly, factors like geopolitical risk and uncertainty are also observed as significant determinant of environmental degradation or panacea to such climate issues. However, the nexus between such risk factors and carbon emission is also missing in this research. Future studies are highly suggested to consider these limitations so that some better empirical outcomes along with the policy implications can be contributed to the existing literature.

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