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Environmental sustainability targets: the role of green investment, ICT development, and economic growth

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ABSTRACT

Current research investigates the role of green investment, information, and communication technology development growth in the Chinese economy's carbon emissions from 1985-2015. This study has applied the quantile autoregressive distributed lagged (QARDL) approach and the Granger-causality in the quantiles to examine the causal linkage between the variables of interest. The findings through QARDL estimation confirm that there is an existence of significant reversion to the long-run equilibrium association between the explanatory variables and CO2. More specifically, the outcomes under long-run estimation confirm that GIN and ICT development plays a significant role in combating the issues like higher CO2 in China. At the same time, more economic growth leads to the destruction of the natural environment with higher carbon emissions. However, the square of economic growth shows some fruitful results towards fighting environmental pollution but not in all the quantiles of the study. Besides, the Granger-causality outcomes confirm the presence of a bi-directional association between green investment, ICT development, economic growth, and its square value. Based on the study findings, some policy implications are also provided. Besides, various limitations are also linked with this study. Firstly, the current study only examines the trends in CO2 emission from the context of China, whereas other regional economies are entirely neglected. Secondly, the factors like governmental influence in controlling carbon emission, environmental regulations, and governance mechanisms are entirely neglected in this research. Thirdly, the robust checking of the empirical findings is also missing in this study. Fourthly, economic uncertainty would also contribute to environmental pollution like CO2. Therefore, it is suggested that future studies should focus on these limitations to provide some meaningful suggestions and literature contributions.

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1. Introduction

The explicit aim of the economies is to accomplish the preferred level of economic growth (EG). However, economies face a number of challenges during its growth and development. Among these challenges, the most common is the environmental damage due to economic activities (Kihombo et al., 2021). EG is measured per head level of production of goods and services. During this production process, different raw materials, i.e., minerals, trees, water, and other natural resources, are extracted from the environment, which leads to environmental degradation (ED) in the form of an increase in greenhouse gas (GHG) emissions. Since economic reforms, the Chinese economy has constantly practiced high EG at an average growth rate of 9.9% during the last three decades. However, China's rapid EG is entrenched in the over-utilization of the resources to a sizable extent (J. Zhang & Liang, 2012). The economy primarily depends on coal as a source of energy. This accounts for around 75% of the total primary energy in China (X.-P. Zhang & Cheng, 2009). Therefore, the carbon emissions also indicate reckless growth with the rapid EG. Hence, the Present study believes that EG plays a significant role in the ED of China. China has surpassed the US to become the biggest emitter of carbon emissions (N. Zhou et al., 2011). According to the yearly report in China's Low-carbon Economic Development (2012), the share of China in overall carbon emission is reached up to 25%.

Being the largest developing economy in the world, China undeniably has a large responsibility and pressure to control carbon emissions with the EG. Hence, China is under huge pressure and has difficulty controlling GHG emissions (Su et al., 2021). Thus, to overwhelm these difficulties, the government of China has fixed a target to reduce CO_2 emissions per unit GDP by 45-50% during the period 2006 to 2020 (Su et al., 2020). To achieve this target, China is vigorously pursuing to apprehend a transformation in economic structure. China believes that economic transformation is crucial in detaching the GHG emissions from EG (Su et al., 2020). The growth of the ICTs industry is important in restricting the economy (J. Zhang & Liang, 2012). In 2008, the European Commission stated that "Information and Communication Technologies (ICTs) have an important role to play in reducing the energy intensity and increasing the energy efficiency of the economy" (Cetin et al., 2018). Several researchers have appreciated the significant effects of the ICT industry in a low-carbon economy (Li et al., 2021). Some researchers recognize ICTs to alleviate global climate change via their ability to improve energy efficiency and reduce renewable energy costs (Asongu & Le Roux, 2017; Weidner et al., 2021). However, other researchers documented that ICTs are detrimental to environmental quality (EQ) because it increases energy use and carbon emissions (Godil et al., 2020; Naderipour et al., 2021; See Figure 1). Hence, the present study expects a significant linkage between ICT and CO_2.

Meanwhile, from the context of the Chinese economy, significant growth has been observed over the last couple of decades. Figure 2 provides the outlook for the patent application in China from 2010 to 2020. It shows that during 2010, the total number of patent application in China were 59,683, which were 224,198 by 2020. It means that a dramatic growth trend in the high-tech industry of China was found. This

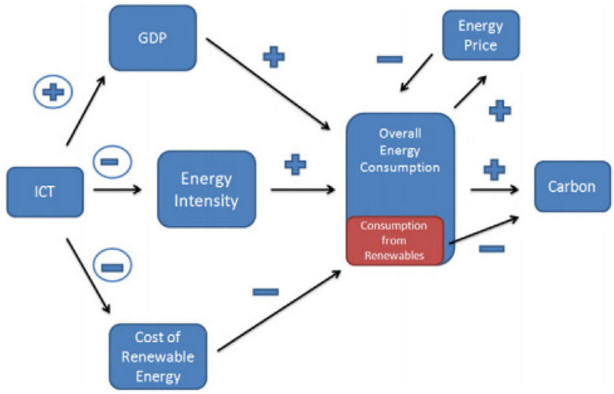

Figure 1. Conceptualizing ICT's impact on CO2.
Source: Moyer and Hughes (2012).

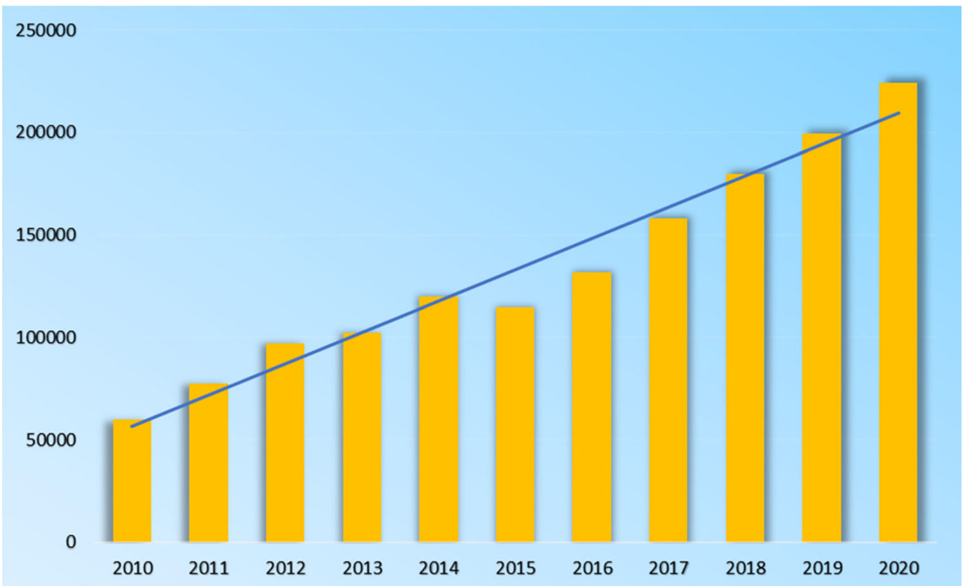

Figure 2. Trends in high-tech industry of China 2010–2020.
Source: Statista (2022).

growth was mainly found in aerospace, telecommunication, electro technologies, computer manufacturers, medical technologies, electro-technologies, etc.

In addition to ICTs, green investments also play an essential role in promoting environmental sustainability. The economy's financial sector is the main pillar of human development (Kendall, 2012). The explicit purpose of the financial sector is to make effective use of global savings. Appropriate use of investments facilitates improvements in the quality of human life (X. Zhou et al., 2020). However, due to the global financial crisis in 2008, people have invested their money in a real-estate bubble and environmentally destructive projects (A. Sachs, 2014), and then the investments become detrimental to human wellbeing. Formerly, the financial sector has

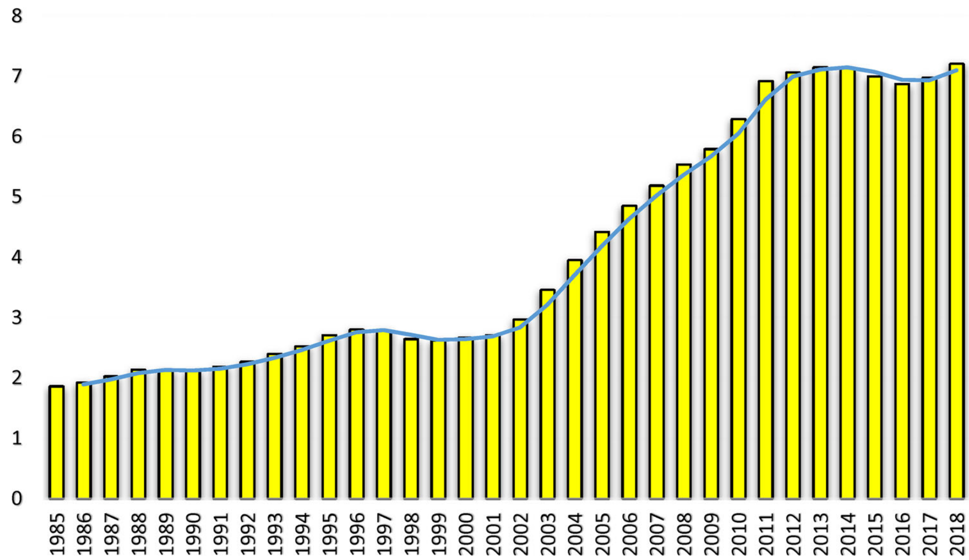

Figure 3. Trends in CO2 emission Per capita in China.
Source: Ritchie and Roser (2019).

overlooked the economic system that facilitates the appearance of falling environmental issues, i.e., climate change, natural resource delectation, habitat, and pollution. The financial sector has recently paid attention to green investments (GI), advancing sustainable economic growth (Umar et al., 2020). According to (J. D. Sachs, 2015), GI is promoted through green finance, which helps achieve a sustainable environment by designing green financial instruments such as green loans for home equity programs and production or construction process green home mortgages, green bonds, climate credit cards, etc. (Ji et al., 2021). Hence, the present study believes that GI is a crucial factor that reduces CO_2 emissions. Figure 3 provides the layout for the CO2 emission per capita in the Chinese economy over the study period (K.-H. Wang et al., 2021). It shows that a growing trend has been observed over the past three decades due to significant industrial and economic growth. The utilization of more energy and emission in the natural environment is quite apparent.

After reviewing the current debate on the modeled variables, this study makes two contributions. First, the study reinvestigates the role of EG and ICT on CO_2 in the case of China because the prior literature exhibits conflicting and contradictory results. Due to the conflicting nature of the results, the present study considers the relationship between these variables by applying a novel approach, i.e., the Quantile ARDL approach, to get the relevant findings. Second, the study investigates the relationship between GI and CO_2 in the case of China. To the best of our knowledge, this relationship is less focused on by the existing researchers, specifically in the context of China. Besides the rest of the paper is organized as follows: Section two deals with the literature review while exploring the relationship between the variables, section three covers research methods and relevant techniques, section four covers results and discussion, and the last section concludes the study.

2. Literature review

2.1. Green investment (GI) and carbon emission (CO_2)

Several researchers refer to green investment (GI) as an environmentally friendly source of investment. Researchers argue that GI is important for climate change as it reduces greenhouse gas emissions (GHG) without declining consumption and production (Eyraud & Lusinyan, 2011). The study on the GI-CO_2 nexus is very limited (Su et al., 2020). Although, there exist some case studies that stress the GI's role in promoting green economic growth and declining emission of CO_2. (J. D. Sachs et al., 2019) investigated the role of GI in attaining SDGs (sustainable development goals). They support the promotion of carbon market instruments such as green funds and green bonds. Further, (Dikau & Volz, 2018) stressed the formation of green financial institutions by promoting green financing and green products using green climate funds (Nassiry, 2019; Tao et al., 2022) highlighted the importance of green financial technology in environmental sustainability and concluded that green financial technology plays a significant role in promoting environmental sustainability. (Hongo et al., 2015; Mirza et al., 2020) also emphasized the positive effects of GI in reducing substantial GHG emissions. The study specified that the development of green finance depends upon different conditions that help capture carbon utilization and storage (Gao et al., 2021). Acquiring "carbon-capturing storage, the role of green finance is vital in promoting green energy. After reviewing the available literature, the present study proposes that:

H_1: There is a negative relationship between green investment and carbon emissions

2.2. Information and communication technologies (ICTs) and carbon emission (CO_2)

A significant number of researchers have explored the effects of ICTs on ED. However, empirical studies in this regard conclude some conflicting results. For instance, some researchers have indicated ICTs as a solution to ED, while some researchers specify that the electronic rays generated from ICTs, pollute the environment (Ielasi et al., 2018). For instance, (C. Zhang & Liu, 2015) utilize the national, provincial, and regional level data of China for 2000-2010 to scrutinize the role of the ICT industry in the level of CO_2 emissions (Ferrat et al., 2021; Mirza et al., 2020). The study applied the STIRPAT model and revealed the significant contributions of the ICT industry in reducing the level of CO2 emissions in China. (Ozcan & Apergis, 2018) examined the role of internet and cellphone usage in air pollution for the case of 20 developing and emerging economies and revealed the significant contributions of internet and cellphone usage in air pollution. (Asongu & Le Roux, 2017) indicated that ICTs are crucial drivers for sustainable economic growth as they have the potential to influence social, economic, and environmental conditions through the provision of virtual substitutes and online management systems. (Weidner et al., 2021) tested the role of ICTs in improving the environmental quality of 43 economies by using mobile phone technologies, telephones, and internet usage as a proxy of ICTs while CO_2 as a proxy of EQ and found the substantial role of ICTs in improving EQ by reducing the level of CO_2. (Berger, 2022; Bhujabal et al., 2021) explored the contributions of ICTs to the GHG emissions of the Asia Pacific region and found a negative linkage between both. They concluded that ICTs reduce GHG emissions by promoting the usage of environmentally friendly sources (Dorfleitner & Grebler, 2022). Similarly, (Avom et al., 2020) covered a negative association between ICTs and the level of CO_2 emissions in the case of 44 African economies (Ferrat et al., 2021). They concluded that ICTs confidently interrelate with globalization to reduce the adverse environmental impacts that promote ES.

However, some researchers contradict with the findings of the aforementioned research. They concluded that ICTs have a 2% share in the deterioration of EQ (N'dri et al., 2021; Naderipour et al., 2021) imply that ICTs positively contribute to the level of CO_2 emissions. Researchers argued that though ICTs tend to increase socio-economic progress, they are highly aligned with environmental deterioration. (Godil et al., 2020) also highlighted the negative environmental effects of ICTs and indicated that ICTs produced a substantial amount of electronic waste per year, which is detrimental to the EQ. (Alataş, 2021) highlighted the adverse effects of ICTs on EQ and indicated that the growth in developing economies' ICTs depends on the imports of restored or second-hand electrical equipment without performing any functionality testing, which produces a large amount of electronic waste that degrades the EQ. (Díaz-Roldán & Ramos-Herrera, 2021) also concluded the negative role of ICTs in the EQ. They indicated that the increase in the consumption of ICTs tends to increase CO_2 emissions. The economic theory proposes a significant role of GI in improving EQ because it enables the industries to get advanced technologies having less contribution to CO2 emission (Shoaib et al., 2020). The utilitarian theory reports that a society's welfare can be enhanced via ICT infrastructure (Withagen & Vellinga, 2001). The theory claims that the welfare of society can be achieved by declining the level of CO2 through ICTs that play an essential role in the ED. Hence, the theory supports a significant link between ICTs and ED.

After reviewing the above literature, the present study considers that although the ICT environment is highly debated among prior researchers, the area still needs to be reinvestigated. Some researchers have revealed its positive influence on ED, while others indicated its negative role in the ED. Though, the study postulates that:

H_2: There is a significant relationship between ICTs and CO_2 emission.

2.3. Economic growth (EG) and carbon emission (CO_2)

The economic growth-environment nexus also received considerable importance from different researchers. Many researchers argue that an increase in annual growth rate is advantageous for the EQ (Alam & Kabir, 2013; Ekins, 2002), while others contradict this argument and indicate that increase in annual growth rate tends to increase the level of GHG emissions, which is unfavorable for the EQ (Kahuthu, 2006; Ozcan et al., 2020; Saidi & Hammami, 2017). For instance, (Lotfalipour et al., 2010) gathered the data on Iran and found a negative relationship between EG and CO_2 emissions. Their study explained that EG is the per head level of production of goods and services, for which an intense amount of energy is required; i.e., the higher the energy consumption, the higher the EG. However, energy consumption is positively aligned with the level of CO_2 emissions that imposes adverse impacts on EQ. Hence, the study concluded a positive affiliation between EG and CO_2. (Bozkurt & Akan, 2014) also indicated a positive connection between EG and CO_2 for the case of turkey during 1960-2010. The study argued that the EG and environmental deterioration are inseparable. (Zameer et al., 2020) also found a negative impact of technological innovation and the positive impact of EG on CO_2. Mesagan (2015) also documented the positive bond between EG and CO_2 in Nigeria. The study explained that the higher level of EG is aligned with the higher level of industrial activities responsible for deteriorating the EQ by increasing CO_2 emissions. (Ozcan et al., 2020) worked on the energy-growth-environment nexus in five OECD economies and observed the positive role of energy and growth in the ED. (Mercan & Karakaya, 2015; Umar et al., 2022) also highlighted the unfavorable effects of EG on the environmental conditions of developing nations. Their study concluded that EG is aligned with different negative externalities that enhance the level of GHG emissions in the environment.

However, some researchers enforce a big question mark on the findings of the above researchers by justifying that economic growth is a kind of *"universal cure"* for all the problems faced by a nation. Researchers argued that EG does not increase environmental deterioration. Instead, an increase in EG improves the EQ by inducing advanced and better technological facilities that are less significantly related to GHG emissions (Park et al., 2018). Many other researchers also concluded the negative relation between EG and CO_2 emissions. For instance, (Malik et al., 2020) observed the negative impact of EG on CO_2 emissions. (J. Li & Li, 2020) explored how the increase in EG reduces the level of carbon emissions. The study indicated the beneficial effects of EG for the EQ by highlighting the negative relationship between EG and CO_2 emissions. The study indicated that EG promotes the technical innovation that escalates energy efficiency, reducing carbon emissions.

After reviewing the above literature, the present study observed that the economic growth-ED nexus had remained a debatable topic among researchers for decades. We observed the conflicting nature of this relation; some researchers concluded its positive role, while others indicated its negative role. Therefore, we believe that there is a need to reinvestigate the relationship between economic growth and environmental deterioration by applying a novel technique. Hence, it is hypothesized that:

H_3: There is a significant relationship between economic growth and CO_2.

Besides, Table 1 summarizes different studies covering the key variables, applied methods, regional implications, and significant findings in recent years.

3. Research methods

Under the present study analysis, the non-linear linkage between CO2, green investment, CIT development, economic growth, and square of economic growth is investigated with the help of an innovative approach named quantile autoregressive distributed lagged or QARDL procedure which was newly introduced by (Cho et al., 2015). One of the core assumptions for using this method is that the study's variables must be nonlinear to explore their linkage through the stated approach. In this regard, the implication of QARDL estimation reflects the key motivation while

Table 1. Literature summary.

Variables	Region	Methods	Findings	Source
Green investment, carbon emission,	Chinese provinces	Cross-section augmented distributed lag approach	Investment in green projects reduces the emission both in the long-run and short-run	(K. Li et al., 2021)
Financial development, natural resource, energy consumption, green investment	China	CS-ARDL	Natural resources and energy consumption are harmful to the natural environment, whereas green investment controls emissions.	(Shen et al., 2021)
Information and communication technologies, carbon emission	Different sectors in China.	Case-study approach	The ICT sector can induce significant amounts of emissions.	(Q. Wang et al., 2018)
ICT, carbon emission	Provincial-level study.	Quantile regression.	Internet penetration has a significant negative effect on carbon emission.	(Chen et al., 2019)
Technology factors, carbon emission	26 European economies	Panel Quantile Estimation	A negative relationship exists between high-tech export and carbon emission.	(Anser et al., 2021)

Source: Author's Estimation.

exploring both long-run and short-run associations between the study variables. Additionally, QARDL is observed as a much better approach to examining the non-linear relationship between the stated variables compared to the orthodox method for analyzing the linear relationship with the help of mean regressed outcome (Godil et al., 2020; He et al., 2021; Jiang et al., 2021; Suki et al., 2020; Sun et al., 2021; Zaighum et al., 2021). Meanwhile, QARDL is quite beneficial in investigating the varying impact of the time services over a series of quantiles. Meanwhile, to check the dependability of the stated quantiles, the Wald test has been applied for both long-run and short-run coefficients. However, the traditional approach to showing the linear ARDL framework can be expressed with the help of following Equation 1.

$$CO2_t = \alpha + \sum_i^p \beta_1 CO2_{t-i} + \sum_i^q \beta_2 GIN_{t-i} + \sum_i^m \beta_3 CIT_{t-i} + \sum_i^n \beta_4 GDP_{t-i} + \sum_i^r \beta_5 GDP2_{t-i} + \epsilon_t \qquad \text{Equation (1)}$$

wherein the above Equation 1, the titles like ϵ_t indicates the white noise residual showing the bottom ground, and P and q show the lagged natural series of the study variables like carbon emission, GIN, CIT, economic growth, and square of economic growth. However, Equation 1 to the quantile framework can provide the following context of the quantile ARDL model, as shown in Equation 2 of the study.

$$Q_{CO2_t} = \alpha(\tau) + \sum_i^p \beta_1(\tau) CO2_{t-i} + \sum_i^q \beta_2(\tau) GIN_{t-i} + \sum_i^m \beta_3(\tau) CIT_{t-i} + \sum_i^n \beta_4(\tau) GDP_{t-i} + \sum_i^r \beta_5(\tau) GDP2_{t-i} + \epsilon_t(\tau)$$

Equation (2)

wherein the above Equation 2, the titles like $\epsilon_t(\tau) = CO2_t - Q_{CO2_t}(\tau/\epsilon_{t-1})$ and $0 < \tau < 1$ are showing the quantiles. For the purpose of data analysis, we have used different quantiles ranging from 0.05^{th} to 0.95^{th}, respectively. Meanwhile, to address the probability of sequential correlation, the above Equation 2 can be adjusted into following Equation 3.

$$Q_{\Delta CO2_t} = \alpha(\tau) + \rho CO2_{t-i} + \varphi_1 GIN_{t-i} + \varphi_2 CIT_{t-i} + \varphi_3 GDP_{t-i} + \varphi_4 GDP2_{t-i} + \sum_i^p \beta_1(\tau) CO2_{t-i} + \sum_i^q \beta_2(\tau) GIN_{t-i} + \sum_i^m \beta_3(\tau) CIT_{t-i} + \sum_i^n \beta_4(\tau) GDP_{t-i} + \sum_i^r \beta_5(\tau) GDP2_{t-i} + \epsilon_t(\tau)$$

Equation (3)

Additionally, the above Equation 3 can be redefined to provide the error correction model for the measurement of the QARDL approach into following Equation 4 of the study

$$Q_{\Delta CO2_t} = \alpha(\tau) + \rho(\tau)\left(CO2_{t-i} - \omega_1(\tau) GIN_{t-i} - \omega_2(\tau) CIT_{t-i} - \omega_3(\tau) GDP_{t-i} - \omega_4(\tau) GDP2_{t-i}\right) + \sum_{i=1}^{p-1} \beta_1(\tau) \Delta CO2_{t-i} + \sum_{i=0}^{q-1} \beta_2(\tau) \Delta GIN_{t-i} + \sum_{i=0}^{m-1} \beta_3(\tau) \Delta CIT_{t-1} + \sum_{i=0}^{n-1} \beta_4(\tau) \Delta GDP_{t-i} + \sum_{i=0}^{r-1} \beta_5(\tau) \Delta GDP2_{t-i} + \epsilon_t(\tau)$$

Equation (4)

In addition, with the help of Δ the method, the cumulative short-term impact of past values of the carbon emission on the current values of the CO2 is also estimated under the present study. Furthermore, the past values of other explanatory variables are also utilized to predict the current values of carbon emission in the economy of China for the short-run estimation. Besides, the study methodology also considers the Granger-causality test to check the direction of causality between the variables of interest.

4. Results and discussion

Findings under Table 2 report descriptive outcomes in terms of mean, data range, standard deviation, and normality scores through J-B stats. The results show that the highest mean score is reported by GDP2, followed by GDP, CO2, and ICT development. At the same time, the green investment represents the lowest mean score showing that compared to the rest of the variables, the low focus is made towards it by the Chinese government during the study period. However, the growth rate in terms of GDP is highest during the study time. In terms of standard deviation, GDP^2 shows a score of 1.059, followed by 1.021's carbon emissions in China. To take into account the normality trends of the study variables, the J-B test is applied where Ho assumes the normal distribution. The findings of the J-B test show that all the variables are showing highly significant output, hence rejecting the normality assumption and

Table 2. Results of descriptive statistics.

Variables	Mean	Min.	Max.	Std. Dev.	J-B Stats
CO2	2.002	1.022	3.002	1.021	19.052***
GIN	0.528	0.025	1.012	0.035	21.010***
ICT	1.041	0.014	2.010	1.012	33.044***
GDP	0.645	0.045	1.065	0.058	23.013***
GDP^2	2.010	1.010	3.003	1.032	18.045***

Note: CO2: carbon dioxide emission; GIN: green investment; ICT: information and communication technologies; GDP: means gross domestic product; GDP2: square of the gross domestic product. The asterisk ***, ** and * represent the level of significance at 1%, 5%, and 10% respectively.
Source: Author's Estimation.

Table 3. Results of unit root test.

Variables	ADF (Level)	ADF (Δ)	ZA (Level)	Break Year	ZA (Δ)	Break Year
CO2	−1.014	−3.101***	−2.031	2005 Q4	−6.010***	2015 Q1
GIN	−0.513	−5.023***	−1.057	2013 Q1	−8.012***	2010 Q2
ICT	1.022	−6.011***	2.023	2011 Q1	−9.011***	2014 Q1
GDP	−0.414	−4.010***	−1.068	2009 Q1	−7.014***	2017 Q2
GDP^2	−1.032	−5.021***	−2.013	2006 Q4	−9.021***	2008 Q4

Note: CO2: carbon dioxide emission; GIN: green investment; ICT: information and communication technologies; GDP: gross domestic product; GDP2: square of gross domestic product.
Source: Author estimation.

supporting the alternative hypothesis, which claims that data is not normal. Therefore, the present study will apply QARDL, for which data is required to be non-normal over time.

Table 3 reports the findings for the unit root test, where it is found that both the augmented dicky fuller test (ADF) and ZA test were applied. The results show that findings for ADF (level) for all the study variables are found to be insignificant. However, the scores for ADF (Δ) for carbon emission, green investment, ICT, economic growth, and square of economic growth are found to be negatively significant at 1 percent. Additionally, ZA at level shows insignificant output, whereas ZA (Δ) has indicated that all variables are negatively significant at 1 percent and the structural breaks. This would justify the argument that all the study variables are stationarity at the first difference and the structural breaks.

The results for QARDL while taking CO2 as the main dependent variable are presented under Table 4 of the study. More specifically, the findings are reported by talking all three ranges of quantiles (lower, medium, higher) for the carbon emission, error correction parameter or p*, long-run coefficients through beta values, t-scores, and short-run coefficients. The findings through QARDL demonstrate that scores for the error correction model (p*) are found to be negatively significant for all the study quantiles except for the lower order. It confirms the existence of reversion to the long-run association between the variables. As observed in the existing literature, various studies have also confirmed the negative and significant output for the ECM to justify the implication of QARDL estimation (Jiang et al., 2021; 2022; Nawaz et al., 2021). In addition, the findings in Table 4 report that βGIN(τ) is significant and negative for all the study quantiles under long-run estimation. This would confirm that higher green investment in China leads to lower carbon emissions, which is a good effort to combat environmental pollution. Li et al. (2021) have considered the Chinese economy and confirmed that investment in green projects is a big source of

Table 4. Results of quantile autoregressive distributed lag (QARDL) for CO_2 emission.

Quantiles (τ)	Constant $\alpha_*(\tau)$	ECM $\rho_*(\tau)$	Long-Run Estimation $\beta_{GIN}(\tau)$	$\beta_{ICT}(\tau)$	$\beta_{GDP}(\tau)$	$\beta_{GDP2}(\tau)$	Short-Run Estimation $\varphi_1(\tau)$	$\omega_0(\tau)$	$\lambda_0(\tau)$	$\theta_0(\tau)$	$\acute{\varepsilon}_0(\tau)$
0.05	−0.013	−0.103	−0.452***	−0.139**	0.152	−0.037	0.433***	−0.015	−0.032*	0.321***	−0.026
	(−0.018)	(−1.020)	(−3.001)	(−2.366)	(1.630)	(−0.066)	(5.026)	(−0.769)	(−1.715)	(3.002)	(−0.033)
0.1	−0.004	−0.104	−0.441***	−0.112**	0.163	−0.028	0.442***	−0.033	−0.029*	0.301***	−0.018
	(−0.016)	(−0.818)	(−2.992)	(−2.425)	(1.620)	(−0.152)	(5.120)	(−1.599)	(−1.822)	(2.991)	(−0.029)
0.2	−0.010	−0.100	−0.447***	−0.110**	0.147	−0.024	0.472***	−0.047*	−0.023*	0.331**	−0.013
	(−0.007)	(−1.109)	(−3.002)	(−2.332)	(1.639)	(−0.544)	(4.822)	(−1.691)	(−1.716)	(1.991)	(−0.010)
0.3	−0.017	−0.205**	−0.432***	−0.128**	0.169*	−0.031	0.454***	−0.031*	−0.038*	0.342**	−0.023
	(−0.017)	(−2.710)	(−2.991)	(−2.428)	(1.641)	(−1.051)	(4.233)	(−1.878)	(−1.919)	(1.961)	(−0.021)
0.4	−0.011	−0.201***	−0.427**	−0.105**	0.158*	−0.041	0.463***	−0.051*	−0.049*	0.312*	−0.009
	(−0.014)	(−3.134)	(−2.899)	(−2.108)	(1.818)	(−0.860)	(4.367)	(−1.672)	(−1.813)	(1.892)	(−0.047)
0.5	−0.019	−0.209***	−0.415**	−0.116*	0.141**	−0.038	0.431***	−0.021*	−0.030	0.323*	−0.019
	(−0.011)	(−3.313)	(−2.595)	(−1.846)	(1.962)	(−0.559)	(4.153)	(−1.801)	(−0.828)	(1.717)	(−0.036)
0.6	−0.009	−0.218***	−0.431**	−0.026	0.161**	−0.042	0.385***	−0.012**	−0.054	0.311*	−0.022
	(−0.008)	(−3.404)	(−2.199)	(−1.465)	(1.979)	(−0.639)	(4.674)	(−1.961)	(−0.714)	(1.649)	(−0.020)
0.7	−0.012	−0.208***	−0.454**	−0.014	0.153***	−0.081**	0.379***	−0.044**	−0.039	0.341	−0.017
	(−0.002)	(−3.509)	(−1.991)	(−1.602)	(2.991)	(−2.042)	(4.063)	(−1.983)	(−1.034)	(1.599)	(−0.007)
0.8	−0.018	−0.210***	−0.429*	−0.032	0.167***	−0.072**	0.343***	−0.037**	−0.060	0.352	−0.010
	(−0.006)	(−3.787)	(−1.891)	(−1.561)	(3.001)	(−2.627)	(3.730)	(−1.971)	(−0.626)	(1.601)	(−0.016)
0.9	−0.023	−0.212***	−0.435*	−0.025	0.159***	−0.066**	0.361***	−0.028**	−0.048	0.338	−0.016
	(−0.001)	(−3.803)	(−1.920)	(−1.259)	(2.992)	(−2.234)	(3.621)	(−1.991)	(−0.637)	(1.470)	(−0.001)
0.95	−0.014	−0.206***	−0.421*	−0.058	0.171***	−0.046*	0.346***	−0.032**	−0.069	0.347	−0.008
	(−0.004)	(−3.308)	(−1.789)	(−1.434)	(3.002)	(−1.924)	(3.240)	(−1.980)	(−0.425)	(1.579)	(−0.008)

Note: CO2: carbon dioxide emission, GIN; green investment, ICT: information and communication technologies, GDP; gross domestic product; GDP2: square of gross domestic product. The table reports the quantile estimation results. The t-statistics are between brackets. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.
Source: Author Estimations.

reducing CO2 in the long and short run. (Huang et al., 2020) have also confirmed that green investment is causing a reduction in the costs under different carbon emission policies.

On the other side, the effect of information and communication technologies development is also showing a significant and negative impact on the CO2 under long-run estimation. This means that more ICT development is a good sign for dealing with the carbon emission in the region of China. In recent years, a significant level of ICT development has been found in China, and similar is justified under lower order and medium order quantiles, where the highest negative impact is recorded as −0.139 for the lowest quantile. Godil et al. (2020) have justified the argument that ICT development helps in reducing environmental pollution for the economy of Pakistan. Haini (2021) has considered ASEAN economies and found that ICT is negative for carbon emission. However, in the research study of (Raheem et al., 2020), the impact of ICT on CO2 is found to be significant and positive, whereas (Amri et al., 2019) have confirmed an insignificant impact of ICT on carbon emission in Tunisia.

In addition, the study findings through QARDL also confirm that GDP is showing its significant and positive impact on CO2 from 0.30^{th} quantile to 0.95^{th} quantile. . It confirms that both growth and environmental pollution are linked with each other. In this regard, research findings as provided by (Waheed et al., 2019) support our argument while claiming that most of the earlier studies have supported that economic growth is a direct source of carbon emission. (Khan et al., 2020) have also observed the economy of Pakistan while claiming that carbon emission is directly linked to economic growth from 1965 to 2015. Besides some other studies also

Table 5. Results of the Wald Test for the constancy of parameters.

Variables	Wald-statistics [P-value]
P	16.551*** [0.000]
β_{GIN}	11.843*** [0.000]
β_{ICT}	3.979*** [0.000]
β_{GDP}	4.010*** [0.000]
β_{GDP2}	1.292 [0.258]
φ_1	8.552*** [0.000]
ω_0	8.969*** [0.000]
λ_0	1.543 [0.186]
θ_0	6.001*** [0.000]
$\acute{\varepsilon}_0$	0.301 [0.861]

Note: CO2: carbon dioxide emission, GIN; green investment, ICT: information and communication technologies, GDP; gross domestic product; GDP2: square of gross domestic product. The p-values are between square brackets. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.
Source: Author Estimations.

explore the nexus between growth and environmental concerns (Hanif, 2018; Kahia et al., 2019; Mikayilov et al., 2018; Q. Wang et al., 2018; Q. Wang et al., 2018).

Furthermore, the influence from GDP2 on CO2 is negatively significant but only for the higher-order quantiles ranging from 0.70th to 0.95th, respectively. This means that GDP square is a good sign in reducing the carbon emission for the economy of China. (Gessesse & He, 2020) indicate that GDP2 is negatively contributing to carbon emission. However, (Dogan & Turkekul, 2016) have considered the economy of the USA while observing the trends in greenhouse gas emissions. Contrary to our findings, their study shows positive nexus between the square of growth and CO2.

According to the findings under short-run estimation, it is found that past and lagged values of CO2 are significantly and positively predict the current and lagged values of the carbon emission in China under each of the study quantiles ranging from lower to higher-order. On the other side, the changes in the past and lagged values of GIN are found to be negatively and significantly linked with carbon emission. However, the highest negative impact is recorded with a coefficient of −0.044. Furthermore, ICT is also significantly and positively linked with current carbon emission values but only for lower and medium order quantiles. On the other side, past and lagged GDP values are positive indicators of current and lagged carbon emission values but only from 0.05th quantile to 0.60th quantile.

Table 5 reports the output for the Wald test to check the constancy of the parameters. Considering the results, the null hypothesis for the speed of adjustment parameter is not supported and is rejected at 1 percent. At the same time, the null of linearity across different tails of each of the study quantiles for the green investment, information and communication technology development, and GDP is also rejected at a 1 percent level of significance. This would justify that the long-run parameters

Table 6. Granger causality in quantile test results.

Quantiles	$\Delta CO2_t \rightarrow \Delta GIN_t$	$\Delta GIN_t \rightarrow \Delta CO2_t$	$\Delta CO2_t \rightarrow \Delta ICT_t$	$\Delta ICT_t \rightarrow \Delta CO2_t$	$\Delta CO2_t \rightarrow \Delta GDP_t$	$\Delta GDP_t \rightarrow \Delta CO2_t$	$\Delta CO2_t \rightarrow \Delta GDP2_t$	$\Delta GDP2_t \rightarrow \Delta CO2_t$
[0.05-0.95]	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.05	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.40	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.70	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.90	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.95	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Source: Authors estimation.

for the study variables are dynamic in different quantiles in the region of China. Meanwhile, the findings for the Wald-statistics for the short run estimation have also rejected the null hypothesis for the linearity of the cumulative influence of past values of carbon emission over the stated quantiles in China.

Finally, Table 6 reports the output for the Granger causality in quantiles. Taking into account the overall quantiles ranging from 0.05^{th} to 0.95^{th}, it is found that there is a bidirectional association between the variables of interest for China. Additionally, the results have also predicted that there is a two-way causality linkage between the carbon emission and green investment, between ICT and carbon emission, between GDP and carbon emission, and between GDP2 and carbon emission.

5. Conclusion and policy suggestions

The current study examines the role of green investment, ICT development, and economic growth in dealing with China's carbon emissions from 1985-2018 with the help of a novel approach named QARDL, as suggested by (Cho et al., 2015). The stated approach is applied as it helps to investigate how the variety of quantiles for green investment, information and communication technology development, and economic growth affect carbon emissions compared to traditional methods like simple OLS or panel estimation techniques. Furthermore, our study has examined the causal association between the variables of interest with the help of the (Troster, 2018) approach. The study findings through QARDL confirm that the error correction parameter is found to be negative and significant for the stated quantiles, which show the presence of significant reversion to the long-run connection between the explanatory variables and carbon emission in China. More specifically, the findings under long-run estimation show that green investment is significantly playing its role in reducing the issue of higher carbon emissions in China. Meanwhile, the impact of ICT on carbon emission under long estimation is also observed as significant and negative. However, GDP turns to show its positive impact in creating more carbon emission whereas GDP squares not. In addition to this, the findings through short run estimation confirm the asymmetric influence of past and lagged values of carbon emission, ICT, green investment, and GDP on the current and lagged values of CO2 as well. Furthermore, the scores through a causal association between the study variables through Granger-causality in the quantiles shows the presence of bi-directional causality between the green investment, ICT, economic growth, and square of economic growth with the CO2 in the region of China.

If the study findings are considered, various policy implications and suggestions can come into existence, specifically from the context of sustainable development. As the environmental quality in the form of carbon emission is prone to deterioration at the increasing level of economic growth, it can be inferred that the growth track in China's region is not under the shadow of sustainability. One of the core reasons for this negative environmental outcome is that the factor of sustainability is neglected by the government and various other concerned departments while going for the production or transportation of goods and services. On the other side, positive influence from the investment in green projects and development in the form of ICT is found to be a solution to combating environmental degradation. For this reason, it is highly suggested that policy-level solutions can be devised based on the different levels of quantiles for both explanatory and outcome variables of interest. Besides, various limitations are also linked with this study. Firstly, the current study only examines the trends in CO2 emission from the context of China, whereas other regional economies are entirely neglected. Secondly, the factors like governmental influence in controlling carbon emission, environmental regulations, and governance mechanisms are entirely neglected in this research. Thirdly, the robust checking of the empirical findings is also missing in this study. Fourthly, economic uncertainty would also contribute to environmental pollution like CO2. Therefore, it is suggested that future studies should focus on these limitations to provide some meaningful suggestions and literature contributions.

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