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RESEARCH ARTICLE

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Investigate the role of technology innovation and renewable energy in reducing transport sector CO_2 emission in China: A path toward sustainable development

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Abstract

The objective of this research is to examine the role of economic growth, technology innovation, and renewable energy in reducing transport sector CO_2 emission in China by using the annual data of 1990–2018. An application of the QARDL approach discloses that economic growth, technology innovation, and renewable energy significantly influence CO_2 emission in the transportation sector in China. Both renewable energy consumption and innovation show a negative impact on emissions of CO_2 related to transport. It depicts that due to the increase in renewable energy and innovation, the CO_2 emission in the transport sector is likely to decrease; however, an increase in the GDP of a country will upsurge the emission of CO_2 in the transportation sector. However, China should make new policies to introduce innovation in the transportation sector to minimize the emission of CO_2.

KEYWORDS
QARLD model, renewable energy, sustainable development, technology innovation

1 | INTRODUCTION

Changes in climate have turned out to be significantly extreme during the last several decades, a hot concern for argument worldwide and a global happening due to the hazard to sustainable advancement (Destek & Sarkodie, 2019; Nathaniel & Khan 2020). Due to a boost in the destruction of environmental pollution that is affecting the whole world resulting in creating environmental issues which in turn constraining the decision related to economic growth and development-associated decisions (Khan et al., 2021; Wang et al., 2020), sustainable growth has now become a key concern for countries. Over a previous couple of decades, environmental contaminants have turned out to be one of the biggest global concerns because of huge boosts in greenhouse gas (GHG) emissions (Khan et al., 2017b; Khan et al., 2017a; Dogan & Seker, 2016). The GHG continues to increase regardless of the projected implications of unabated variation in climate. Development of an economy cannot be attained without an influence on the surroundings, as Deviren and Deviren (2016) and Esso and Keho (2016) put it. CO_2 emissions (CO_2_EMS) and economic growth (ECO_GRW) had substantial policy implications for the environment. CO_2_EMS has been a leading issue, and all efforts have been put to eliminate it. This boom is attributable to enhanced day-to-day human pursuits (Kaplan, 2015). The world's populace is growing continuously and requires an increase in goods and services; therefore, the nexus between emissions and population has been a concern of consideration (Scovronick et al., 2017; Khan & Qianli 2017a). Moreover, activities performed at the industrial level require higher consumption of fossil fuel as well as energy consumption which results in higher emission of CO_2 in the process of production and technological development as well (Szklo & Schaeffer, 2007), which consequently contribute to environmental degradation.

With a swift increase in population which results in economic advancement and technological progression, the requirement for energy in developed and developing nations has enhanced. According to Saidi and Ben Mbarek (2016), though energy consumption (EN_CON) can result in ECO_GRW, it is the primary cause of environmental degradation. With the advancement of the industry, CO_2_EMS, in specific, has sharply boosted (Chen, 2016). Furthermore, according to the anticipation of IPCC (2007), CO_2_EMS, that is, specifically related to energy, will increase between 40 and 110% by 2030. Hence, it is vital to examine the EN_CON that is related to the aspects that affect variations in CO_2_EMS to comprehend energy conservation and emission minimization to achieve an economy with low carbon.

A larger number of studies have focused on EN_CON and ECO_GRW considering them as the key variables responsible for CO_2-EMS. However, following the study of Zhang (2010), it was found that EN_CON and ECO_GRW alone may fail to clarify variations in CO2_EMS. Indeed to achieve sustainable economic advancement, nations have switched their focus to the growth and application of renewable energy (REN_EN) consumption. Sadorsky (2009) found that we will be dependent on REN_EN consumption in the future. In 2014, REN_EN accounted for 19.2% of the global final EN_CON. The IEA forecasted that REN_EN consumption will be the speediest growing aspect of worldwide energy needs (Chen & Lei, 2018). Quite some nations are interested in the reduction of CO_2_EMS and EN_CON along with improving the productivity of the manufacturing industries (Zhang, Zhou, & Kung, 2015). According to Ramli, Muis, Ho, Idris, and Mohtar (2019), REN_EN plays a key role in environmental concerns as it is classified as a fuel source with no-emission, which can be utilized as alternative traditional fossil fuels. Policymakers have recognized the significance of minimizing CO_2_EMS in making national policies related to energy and economy, which demands insight into the behaviors of CO_2_EMS and checking emission performance.

Innovation has also been pronounced as an essential factor in economic advancement. Economic development dependent on technology is most evident in various industries (Anser et al., 2020a). As nations struggle to progress, there is a boost in their economic actions which cause an increase in EN_CON, as a result, spurring CO_2_EMS. Ignoring the effect of the environment on progress is in no way advantageous. There are several channels by using which innovations can impact emissions. Innovation stimulates improvements in productivity and growth of an economy and triggers a shift in the direction of low-carbon energy. Besides, innovation speeds up technical advancement as it enables better economic output while utilizing the identical amount of other inputs. According to Long, Chen, Du, Oh, and Han (2017), environmental innovation positively influenced the economic and environmental functionality of Korea-owned businesses in China.

The influence of information and communication technology (ICT) on the community has grown to be a hot concern of debate during the last couple of years. The growing significance of ICT would probably reshape modern society, and it would also lead to the consequence of the upcoming civilization. ICT forms the basis for tracking climate variation, mitigating and adjusting its consequences, and aiding in the changeover to a green economy. ICT is vital for industrialization, eventually affecting environmental quality and ECO_GRW (Khan & Qianli 2017b; Danish, Baloch, Saud, & Fatima, 2018).

Irrespective of the uplifting role of ICT in economic advancement (Toader, Firtescu, Roman, & Anton, 2018), little consideration has been given to the potential environmental implications of ICT, such as mobile, satellites, phones, and the Internet. The role of all these is quite significant in dealing with the principle challenges concerning climate transform and sustainable advancement. Moreover, Zhou, Zhou, Wang, and Su (2019), found that it is crucial to perceive the CO_2_EMS effects of ICT in the current digital age while dealing with climate change problems.

Kang, Zhao, and Yang (2016), found that technology is providing the platform for the world to get closer and aiding to fix the predicaments. It is noted that environmental degradation enhances the growth of the economy but decreases with technological advancement. Technical innovation (TEC_INV) is also vital in enhancing energy efficiency (Hang & Tu, 2007; Khan et al., 2021a; Nan, Levine, & Price, 2010); it is an aspect that is worthy of our consideration when we browse the main determinants of CO_2_EMS. The latest technology facilitates the economy to generate a level of productivity that consumes low energy (Sohag, Begum, Abdullah, & Jaafar, 2015) and hence reduces CO_2_EMS. Additionally, technological advancement could result in quicker acceptance of REN_EN to encounter energy demands and alter the energy utilization structure.

Additionally, ECO_GRW also leads the country to produce more products and services, specifically with ICT usage (Anon Higón et al., 2017), and ECO_GRW is likely to enhance ICT products and services, due to which CO_2_EMS upsurges. However, the environmental Kuznets curve (EKC) hypothesis claims that, at first, pollution aggravates with per capita increase but subsequently more income reduces pollution (Anser et al., 2020b; Khan et al., 2020a). Economic advancement has effects on the environment through three channels. Initially, the income through the scale effect damages the environment and compromises technological change and economic structure (Khan et al., 2020b; Andrée, Chamorro, Spencer, Koomen, & Dogo, 2019). Secondly, the composition effect reduces the damaging impacts of income through structural modifications in the economy. Finally, the influence decreases pollution because of adopting the innovations that are environmentally friendly and further application of rigorous environment-related standards; this is acknowledged as the technique effect. The technique and composition effect dominates the scale effect and leads to the inverted U-shape nexus between pollution and income. The concept of EKC was extensively explored; some researchers validated its presence (e.g., Dehghan Shabani & Shahnazi, 2019; Danish et al., 2019; Pata, 2018), while some researchers have refused its occurrence (Belloumi et al., 2017; Amri, 2018).

Among the nations in Asia, China is the leading and transitional economy. It has a "veto" power among the nations of the UN Security Council and belongs to communist believers. China is at the Stage-2 level of development among 137 nations, as per the review of the Global Competitiveness Index 2017–2018, issued by the World Economic Forum. The population of China was 1.437 million by March-2020 (China Population—Worldometer, 2020). In 2019, total energy consumed (standard coal) was approximately 4.64 billion metric tons. In 2018, CO_2_EMS in China was approximately 9,232.6 million tones accounted for 27.6% of the world total, while in 2017, the total primary consumption of energy (oil) was 3,132.2 million tones equal to 23.2% of the world total, making China the chief consumer of energy in the world (BP Statistical Review of World Energy, 2018; International Energy Agency. World Energy Outlook, 2013).

According to Nan et al. (2010), China is the source of more than 1/4 of global CO_2_EMS, further, according to Sohag et al. (2015), a great deal of expansion in CO_2_EMS was due to the demand for heat and electricity. Transportation is an underlying requirement for a society's advancement and growth of an individual's life. The CO_2_EMS in the field of transport has drawn the focus of policymakers simultaneously in the field of climate change and transport, considering the portion in total emissions and consistent growth. As the Chinese economy evolved in recent decades, the significance of transport (specifically the road one) has been noticed for both prolonged ECO_GRW and the advancement of lifestyle. According to Wang (2000), freight and passenger transportation has boosted by 8 and 15 times, respectively, throughout the preceding two decades. In China, road transport has steadily become the leading portion of the transportation structure. As an outcome, road transportation utilizes oil and releases a huge quantity of CO_2 (He et al., 2005). If one compares the utilization of oil by road transport system of China with that of total oil utilization, it was found to be much lower than in developed countries. However, the availability of fuel might become a challenge for China because of the swift growth of road transport.

The transportation sector emits about 1/4 of the world's CO_2_EMS (IEA, 2011). The CO_2_EMS of developed economies due to the transport sector has turned out to be a significant reason for the domestic CO_2_EMS. CO_2_EMS China's transport sector has also considerably elevated due to the swift boost in the number of vehicles. Since 1990, the transport segment which has already been liable for an eightfold rise in final oil utilization (PBL Netherlands Environmental Assessment Agency, 2013) could be a significant contributor to CO_2_EMS growth, due to sales of new passenger cars attaining about 2.6 million by the end of 2019 (IEA, 2019). Thus Chinese road TCO_2_EMS, which happened to be less than 300 Mt in 2007 (Ou, Zhang, & Chang, 2010), could expand to become a significant contributor to worldwide CO_2_EMS by 2050.

According to the National Development and Reform Commission, (2004), in 1994, the CO_2_EMS of China's transport sector was 166 MT, which was approximately 5.40% of the total CO_2_EMS. The official figures of transport EN_CON of China only consist of the EN_CON of automobiles employed in commercial functions but exclude the consumption by noncommercial means (such as company-owned automobiles, private automobiles, and government-owned automobiles) (Wu, 2007; Geng et al., 2009), which is the principal source of transport CO_2_EMS (TCO_2_EMS) of China. The lack of detail related to fuel consumption in road transportation is the main hurdle for figuring out CO_2_EMS in the transport industry. China's Ministry of Environmental Protection established the first China Pollution Source Census, which was completed in 2010 and collected comprehensive facts from 1.58 million establishments which include fuel consumption particulars at the facility level.

Although energy and CO_2_EMS efficiency in many areas have been extensively reviewed in China, a couple of researches have centered on the transportation business (Zhang, 2013). There were also much fewer studies and discussions carried out at the local level (Cai et al., 2012). Analyzing the costs and strategies related to the reduction in CO_2_EMS and the possibilities of implementing a variety of low-carbon innovations in this segment is subsequently of vital significance.

Zhou et al., (2013), have measured the performance of CO_2_EMS of the territorial transportation industry and revealed that the efficient areas have reduced since 2004, and in 2006, it has reached the lowest record while it was again improved afterward. Chang et al., (2013) measured the ways for CO_2_EMS and prospective reductions for the local transport industry; the outcomes revealed that the majority of the regions in China do not own a transportation industry that is eco-efficient. Zhou, Chung, and Zhang (2014), researched the energy efficiency and possible energy savings for the industry related to the transport of China by utilizing the DEA method. They found that cumulative energy saving was nearly 2.75% of the energy utilized in transport. Zhang Liu, (2015) found that the reduction in performance of CO_2_EMS is due to technological downfall.

Several studies have presented situations for EN_CON and CO_2_EMS in the transport industry of China. There are CO_2_EMS and EN_CON situations for transport and other industries from 2005 to 2050 with different models presented by, for example, (Chen, 2005). These research studies divide the transport sector into 10 modalities (railway, air, bus, waterway, and car for the passengers, and railway, waterway, air, and pipeline for freight transport).

In a study, Wang, Zhang, and Zhou (2011) calculated the demand for freight transport services concerning passenger transport and economic activity on predicted mean kilometers covered by different modes such as train, bus, etc. The projections were till 2050. Different energy saving possibilities were analyzed by Fu (2011) concerning the situations that are related to the betterment of energy efficiency. Other researchers such as Liu, Ma, Ren, and Zhao (2020), have also evaluated CO_2_EMS and EN_CON from an international viewpoint.

The existing research adds up to the existing literature as being a founding effort that examines the nexus between EC_GRO, TEC_INV, and REN_EN with TCO_2_EMS in China. Earlier studies could not be perceived as conclusive simply because these types of variables were not researched in the nexus of TCO_2_EMS. Keeping this fact in mind, this work examines the causal nexus of these factors to further suggest policy guidelines based upon the outcomes. Even though it is challenging to visualize the advancement of the TCO_2_EMS and its nexus with EC_GRO, TEC_INV, and REN_EN, still, it is to express more actionable and potential approaches to assist the business network and express the future approaches in line with the real scenario.

Experts in earlier studies had concentrated on the implementation of appropriate methodology to deal with the gaps but the usage of QARDL in this work has made it distinct from the earlier work. The current empirical research studies have considered the traditional research techniques such as exploring the causation among the said variables while neglecting the quantiles. Therefore, final policy implications cannot be adopted based on inappropriate and inconsistent results. However, the existing study utilizes a more refined and best-suited methodology to broaden the examination by adding new comprehensions to the EC_GRO, TEC_INV, and REN_EN with TCO_2_EMS nexus. Such insights authenticate the choice of the QARDL approach to link up these hardships of agreement hence bordering all the specified gaps. The existing research is to institute this strategy to reassess the nexus among EC_GRO, TEC_INV, and REN_EN with TCO_2_EMS.

The QARDL method substantially differs from the previous methods because of its being more extensive and superior to linear models. This superiority is based on a couple of grounds. Initially, locational asymmetries are considered in this model, where outcomes and the factors may be contingent on the state of the dependent variable, that is, TCO_2_EMS within its conditional distribution. Subsequently, the QARDL technique concurrently takes into account the long-term nexus of EC_GRO, TEC_INV, and REN_EN with TCO_2_EMS, and its associated short-term characteristics over the quantiles ranges of the conditional dissemination of TCO_2_EMS.

Lastly, in contrast to the present research, a couple of specific investigations discover a sign of the absence of cointegration in between these time series, at the time of implementing conventional econometric techniques, such as the linear ARDL model. This shortcoming could conveniently be elaborated by the accessibility of measurement related to quantile varying cointegration at the short-term level, irrespective of the point that, in long run, the factors remain moving constantly (Xiao, 2009). In the QARDL model, because of the shocks, the cointegrating coefficient shifts over the quantile.

The QARDL is also superior over the models formulated by Shin, Yu, and Greenwood-Nimmo (2011), that is, NARDL—Nonlinear Autoregressive Distributed Lag model in which nonlinearly is determined by setting up the intensity level at zero in contrast to the QARDL model where it is set up according to the data-driven procedure. Due to these powerful proofs, the QARDL methodology turns out to be most appropriate for asymmetric and nonlinear nexus of EC_GRO, TEC_INV, and REN_EN with TCO_2_EMS in China.

The outstanding sections of this paper are set in the following manner: Section 2 includes the review of the previous literature; Section 3 discusses data analysis; estimations, result from analysis, outcomes, and related discussion are revealed in Section 4, and at last in Section 5, policy implications have been advised.

2 | LITERATURE REVIEW

Environmental pollution has become a global concern that requires a focused effort to minimize the CO_2_EMS threat. Each association adopts a different tactic to deal with the issues related to carbon, and the stimuli behind the acts have been hypothesized and contended (Raybould, Cheung, Connor, & Butcher, 2020). Many pieces of research have been carried out on the nexus between CO_2_EMS and ECO_GRW. Grossman & Krueger, (1991), formulated the EKC hypothesis which explains that ECO_GRW and environmental degradation (gauged by CO_2_EMS) have nonlinear nexus and are inverted-U-shaped. It reveals that ECO_GRW prospects to an on-going degradation of the surroundings but after a certain point of ECO_GRW, it begins to get better again. Similar consequences were discovered in the research studies of (Kais & Sami, 2016; Khan et al., 2018; Khan et al., 2019b; Zhu, Xia, Guo, & Peng, 2018). A variety of proxies of ECO_GRW upsurges CO_2_EMS have been validated in many types of research like (Chang, 2010; Chebbi, 2010; Shiyi, 2009).

A couple of the experts reported the negative or mixed influence of ECO_GRW on CO_2_EMS (Chandran & Tang, 2013; Sharma, 2011). Liobikienė et al (2019) revealed in their research on 147 nations that GDP contributes toward the reduction of CO_2_EMS only through energy efficiency. For the same reason, nations should focus on technological advancement and energy efficiency as they look for sustainable ECO_GRW. According to Talbi (2017), energy efficiency has a principal role in lowering CO_2_EMS, his conclusions contrast to that of Liobikienė and Butkus (2019) on ECO_GRW in CO_2_EMS reduction observance.

However, Egbetokun et al. (2020) discovered N-shaped nexus between ECO_GRW and CO_2_EMS. The fall of EKC after the level from where income increases are not fixed and if environmental legislation and technical innovation are not urged, then community falls into a trap of obsolescence that is related to technology where society reverts to growing environmental pollution ahead of the EKC (Balsalobre-Lorente, Shahbaz, Tiwari, & Jabbour, 2018). This even further stresses the inclusion of energy innovation and tight environmental guidelines into the advancement process at all phases to abstain from the influence of technical obsolescence.

Dogan & Turkekul, (2016), unveiled EN_CON into the nexus between CO_2_EMS and ECO_GRW and discovered the nonexistence of the EKC hypothesis. Expert, for example, Dogan et al, (2016), viewed the existence of causality (i.e., bidirectional) between CO_2_EMS and ECO_GRW. In fact, existing research studies were also unsuccessful in finding the pieces of evidence related to the impact of ECO_GRW on CO_2_EMS (Chen & Lei, 2018).

The impact of EN_CON on CO_2_EMS is also questionable. Jayanthakumaran, Verma, and Liu (2012) highlighted that, in China, among others, income and EN_CON are some of the reasons for CO_2_EMS. Accordingly, attainment of swift economic growth is possible through consumption of energy at a higher rate than eventually causing CO_2 emission that links to influence the environment (Khan, Ali, Kirikkaleli, Wahab, & Jiao, 2020; Khan et al., 2018). In line with this, a higher rate of energy consumption causing an increase in the allocation of energy resources in order to perform production activities which are viewed as a critical aspect for investment and growth (Edame & Okoi, 2015). Despite economic development, utilization of resources has a detrimental effect on environmental quality due to the consumption of energy and fossil fuel causing an increase in emission of CO_2 (Razzaq, Sharif, Ahmad, & Jermsittiparsert, 2020). Though economic growth is of importance for countries on one side, yet the sustainability of future generations on the other side emerges as one of the challenges for both developing as well as developed countries. Few scholars determined that total EN_CON has a direct influence on CO_2_EMS (Dogan et al., 2016, Wang, Li, Fang, & Zhou, 2016). Whereas, as per Omri (2013), there was causality, that is, (unidirectional) from EN_CON to CO_2_EMS. Some, for example, (Ben Jebli, Ben Youssef, & Ozturk, 2016, Sulaiman et al., 2013) also discovered that REN_EN consumption lessened CO_2_EMS. Farhani & Ben Rejeb, (2012), and López-Menéndez, Pérez, and Moreno (2014), endorsed that REN_EN consumption has a direct influence on CO_2_EMS. Additionally, Chiu & Chang, (2009) believed that REN_EN consumption and GDP added to CO_2_EMS for a lower threshold, while REN_EN usage lessened the CO_2_EMS for the upper threshold.

The environmental influence of ICT has continued to be a hot point of discussion for the last couple of years. Lennerfors, Fors, and van Rooijen (2015), found that the introduction of transport structure, smart metropolitan areas, manufacturing procedure, and energy-saving benefits on an international scale are supposed to minimize the level of CO_2_EMS. ICT in numerous areas of the economy, (e.g., power, transport, energy, financial and agriculture, etc.) also lowers CO_2_EMS. Furthermore, the utilization of machines that reduce labor work can be beneficial in the reduction of CO_2_EMS rather than utilizing labor at a big scale and mechanization in various sectors (Salahuddin and Alam, 2015).

China has attained excellence in technology especially because of steeper ICT insight and a boost in the Foreign Direct Investment (FDI). Due to FDI, China has introduced the latest technologies. More advancement of this market would enhance the development of increasing digital businesses and create the essential condition to initiate new ones. The contribution of China in the advancement of the technology industry might generate favorable spillovers to the traditional technology giants (World Economic Outlook, 2018).

The research on the nexus between ICT and CO_2_EMS is broken down into two constituents. In the first one, the experts have determined that ICT mitigates the degree of CO_2_EMS (Lu, 2018). Furthermore, Ozcan & Apergis, (2017), determined the influence of Internet usage on CO_2_EMS in growing nations. The outcomes of a specific study suggest that Internet utilization reduces the probability of air pollution. A study about the influence of online shopping on CO_2_EMS simultaneously in developing and developed nations was undertaken by Al-Mulali et al. (2015). The scientific outcomes indicate that due to Internet utilization, outdoor exercises are minimized, which results in the reduction of EN_CON and ultimately in TCO_2_EMS in developed nations.

However, online shopping is not that beneficial in developing nations due to the slow speed of the Internet. Recent research by Shahnazi and Shabani (2020), mentioned the inverted U-shaped nexus between ICT and CO_2_EMS on an international scale in the case of Iran and revealed that in the initial stage of advancement of ICT, it deteriorates the environmental standard, but, pollution decreases with more advancement in the ICT field.

Long, Luo, Wu, and Zhang (2018) determined that innovation fails to disturb CO_2_EMS in BRICS nations. Similarly, Yu and Du (2018), and Wang, Sun, and Wang (2018) noticed that advancement in energy technology has a significant role in the reduction of CO_2_EMS. The result of Balsalobre-Lorente, Shahbaz, Roubaud, and Farhani (2018) research on EU-5 for the years covering 1985–2016 revealed that energy innovation stimulates a quality environment. In support of this notion, Samargandi (2017) found that significant technology innovation in manufacturing will eventually minimize the damaging impact of emissions. Furthermore, from the empirical viewpoint, Yii et al., (2017), evaluated the causal nexus between CO_2_EMS and technology innovation in Malaysia. The research covered the period from 1971–2013, and the researchers discovered that technology innovation has an indirect relation, that is, (negative) with CO_2_EMS in the short run, recommending that policy initiators enhance innovation-related research to augment environmental sustainability and ECO_GRW.

Also, Mensah et al. (2018) along with other variables reviewed the nexus between GDP, REN_EN consumption and R&D, and CO_2_EMS. The findings on 28 OECD nations revealed that GDP increases CO_2_EMS, whereas, R&D decreases emissions and improves the quality of the environment. They determined that innovation is a crucial element in the minimization of CO_2_EMS throughout these countries. The influence on pollution due to Internet retailing was analyzed by Al-Mulali, Sheau-Ting, and Ozturk (2015). The study includes 77 nations for the period of 2000 to 2013. CO_2_EMS was taken as a proxy for pollution, and the outcomes indicated that electricity consumption, GDP growth augment CO_2_EMS simultaneously in developed and developing nations. But, CO_2_EMS reduces due to internet retailing in the case of developed nations but does not have a considerable influence on CO_2_EMS in developing nations. At the same time, Lee, Lee, and Ning (2016), found that the second idea of research is related to the adverse influences on the environment due to ICT. The usage of ICT induces CO_2_EMS (Khan 2019; Khan, Baloch, Saud, & Fatima, 2018; Khan et al., 2019b; Salahuddin, Alam, & Ozturk, 2016). Further, Lee et al., (2014), proved in the case of ASEAN nations that ICT leads to both ECO_GRW and CO_2_EMS.

3 | METHODOLOGY

The QARDL method explored by Cho et al. (2015) was applied to analyze the vibrant influence of EC_GRO, TEC_INV, and REN_EN on TCO_2_EMS in China. This is the extension of the ARDL model which permits the analysis of the asymmetries and nonlinear nexus between the EC_GRO, TEC_INV, and REN_EN on TCO_2_EMS. The following Equation (1) shows its initial form.

$$TCO2_t = \mu + \sum_{i=1}^{p} \upsilon_{TCO2i} TCO2_{t-i} + \sum_{i=0}^{q} \upsilon_{GDPi} GDP_{t-i} + \sum_{i=0}^{r} \upsilon_{GDP^2 i} GDP^2_{t-i} + \sum_{i=0}^{U} \upsilon_{INVi} INV_{t-i} + \sum_{i=0}^{v} \upsilon_{RENi} REN_{t-i} + \epsilon_t \tag{1}$$

where ϵ_t is clarified as $TCO2_t$ – $E\ [TCO2_t/\Phi_{t-1}]$ with ϵ_{t-1} is the smallest γ-field attributable to {$TCO2_t$, GDP_t, GDP^2_t, INV_t, REN_t, $TCO2_{t-1}$, GDP_{t-1}, GDP^2_{t-1}, INV_{t-1}, REN_{t-1}} and *p, q, r, u, and v* are the lag orders specified by the (SIC), that is, Schwarz information criterion. In Equation (1) TCO_2, GDP, GDP^2, INV, and REN are TCO_2_EMS, gross domestic product and square, TEC_INV, and REN_EN.

About quantile, the comprehensive model of QARDL (p,q,r,s,v) for the Equation (1) is:

$$Q_{TCO2t} = \mu(\tau) + \sum_{i=1}^{p} \upsilon_{TCO2i}(\tau)\, TCO2_{t-i} + \sum_{i=0}^{q} \upsilon_{GDPi}(\tau) GDP_{t-i} + \sum_{i=0}^{r} \upsilon_{GDP^2 i}(\tau) GDP^2_{t-i} + \sum_{i=0}^{U} \upsilon_{INVi}(\tau) INV_{t-i} + \sum_{i=0}^{v} \upsilon_{RENi}(\tau) REN_{t-i} + \epsilon_t(\tau) \tag{2}$$

where, $\epsilon_t(\tau) = TCO2_t - Q_{TCO2_t}\ (\tau/\forall_{t-1})$ (Kim and White, 2003) and $0 > \tau < 1$ clarifies the quantile.

Due to the consequence of the probability of serial correlation in the error term, in Equation (2), the QARDL can auxiliary be written as:

$$Q_{\Delta TCO2t} = \mu + \rho TCO2_{t-1} + \kappa_{GDP} GDP_{t-1} + \kappa_{GDP^2} GDP^2{}_{t-1} + \kappa_{INV} INV_{t-1} + \kappa_{REN} REN_{t-1} + \sum_{i=1}^{P} \upsilon_{TCO2i} \Delta TCO2_{t-i} + \sum_{i=0}^{q} \upsilon_{GDPi} \Delta GDP_{t-i} + \sum_{i=0}^{r} \upsilon_{GDP^2 i} \Delta GDP^2{}_{t-i} + \sum_{i=0}^{U} \upsilon_{INVi} \Delta INV_{t-i} + \sum_{i=0}^{v} \upsilon_{RENi} \Delta REN_{t-i} + \epsilon_t(\tau) \tag{3}$$

According to the framework of QARDL, the modified form of Equation (3) as per Cho et al., (2015) for ECM is:

$$Q_{\Delta TCO2t} = \mu(\tau) + \rho(\tau)\big(TCO2_{t-1} - \beta_{GDP}(\tau) GDP_{t-1} - \beta_{GDP^2}(\tau) GDP^2{}_{t-1} - \beta_{INV}(\tau) INV_{t-1} - \beta_{REN}(\tau) REN_{t-1}\big) + \sum_{i=1}^{P} \varphi_i(\tau) \Delta TCO2_{t-i} + \sum_{i=0}^{q} \boldsymbol{\delta}^{GDP_I}(\tau) \Delta GDP_{t-i} + \sum_{i=0}^{r} \boldsymbol{\vartheta}^{GDP^2{}_I}(\tau) \Delta GDP^2{}_{t-i} + \sum_{i=0}^{U} \boldsymbol{\omega}^{INV_I}(\tau) \Delta INV_{t-i} + \sum_{i=0}^{v} \boldsymbol{\lambda}^{REN_I}(\tau) \Delta REN_{t-i} + \epsilon_t(\tau) \tag{4}$$

The delta technique was utilized to gauge the cumulative short-run influence of the earlier TCO_2_EMS on present TCO_2_EMS. It was presented by φ. Likewise, the aggregate short-run influence of previous and prevailing EC_GRO, TEC_INV, and REN_EN on the contemporary level of TCO_2_EMS was gauged by $\boldsymbol{\delta}_{\mathbf{o}}^{GDP_*} = \sum_{i=1}^{q} \boldsymbol{\delta}_{\mathbf{o}}^{GDP_i}$, $\boldsymbol{\vartheta}_{\mathbf{o}}^{GDP^2{}_*} = \sum_{i=1}^{u} \boldsymbol{\vartheta}_{\mathbf{o}}^{GDP^2{}_i}$, and $\boldsymbol{\omega}_{\mathbf{o}}^{INV_*} = \sum_{i=1}^{v} \boldsymbol{\omega}_{\mathbf{o}}^{INVi}$. $\boldsymbol{\lambda}_{\mathbf{o}}^{REN_*} = \sum_{i=1}^{r} \boldsymbol{\lambda}_{\mathbf{o}}^{REN_i}$.

In, for example, (4), the sign of the parameter ρ needs to be negative and significant. The long-run cointegrating parameter for EC_GRO, TEC_INV, and REN_EN is β. The following formula has been utilized:

$$\beta_{GDP*} = -\frac{\beta_{GDP}}{\rho}, \beta_{GDP^2*} = -\frac{\beta_{GDP^2}}{\rho}, \beta_{INV*} = -\frac{\beta_{INV}}{\rho}, \beta_{REN*} = -\frac{\beta_{REN}}{\rho}$$

With the utilization of the Wald test, the researchers have analyzed the statistical short- and long-run asymmetric impact of EC_GRO, TEC_INV, and REN_EN on TCO_2_EMS. For example, in the case of ρ, that is, the parameter for speed of adjustment, the null hypothesis is,

ρ_* (0.05) .... = ρ_* (0.95). The identical line of course was employed for β_{GDP}, $\beta_{GDP}{}^2$, β_{INV}, and β_{REN} parameters and for the lags displaying the short-term parameters, $\boldsymbol{\delta}_{\mathbf{o}}^{GDP}$, $\boldsymbol{\vartheta}_{\mathbf{o}}^{GDP^2}$, $\boldsymbol{\omega}_{\mathbf{o}}^{INV}$, and $\boldsymbol{\lambda}_{\mathbf{o}}^{REN}$.

TABLE 1 Outcomes of descriptive statistics

Variables	TCO_2	GDP	INV	REN
Mean	7.291	3,256.010	299,431.300	21.793
Minimum	4.877	729.161	5,832.000	11.696
Maximum	9.256	7,752.560	1,393,815.000	34.084
SD	1.414	2,205.158	427,511.300	8.665
Skewness	−0.436	0.636	1.425	0.062
Kurtosis	1.755	2.060	3.651	1.245
Jarque-Bera	46.793	23.023	10.330	18.739
Probability	0.000	0.000	0.006	0.000

Source: Authors Estimation.

TABLE 2 Outcomes of Unit Root test

Variable	ADF (level)	ADF (Δ)	ZA (level)	Year	ZA (Δ)	Year
TCO2	0.245	−4.014***	−1.187	2005	−5.088***	2011
GDP	−0.902	−4.612***	−2.214	2012	−7.269***	2009
INV	0.290	−4.327***	−0.852	2009	−5.432***	2012
REN	0.586	−3.389***	−1.275	2016	−9.074***	2017

Note: The figures in this matrix state the ADF and ZA tests' statistics for stationarity property. ***, **, and * indicate a level of significance at 1%, 5%, and 10%, respectively. The critical values for the ZA test are −5.57 (1%), −5.08 (5%), and −4.82 (10%), respectively.
Source: Authors Estimation.

TABLE 3 Results of Quantile Autoregressive Distributed Lag (QARDL)

Quantiles (τ)	$\alpha_*(\tau)$	$\rho_*(\tau)$	$\beta_{GDP}(\tau)$	$\beta_{GDP}{}^2(\tau)$	$\beta_{INV}(\tau)$	$\beta_{REN}(\tau)$	$\varphi_1(\tau)$	$\delta_o^{GDP}(\tau)$	$\vartheta_o^{GDP^2}(\tau)$	$\omega_o^{INV}(\tau)$	$\lambda_o^{REN}(\tau)$
0.05	0.156***	−0.082***	0.314***	−0.046	−0.158**	−0.279**	0.762***	0.113**	−0.006**	−0.256***	−0.102***
	(0.037)	(0.008)	(0.037)	(0.031)	(0.066)	(0.141)	(0.134)	(0.053)	(0.002)	(0.089)	(0.018)
0.10	0.270***	−0.215***	0.284***	−0.057**	−0.158***	−0.194	0.965***	0.113**	−0.004**	−0.409***	−0.119***
	(0.027)	(0.022)	(0.067)	(0.024)	(0.044)	(0.136)	(0.269)	(0.042)	(0.002)	(0.134)	(0.037)
0.20	0.085***	−0.252***	0.236***	−0.058**	−0.208***	−0.160*	0.997***	0.113**	−0.001	−0.478***	−0.051**
	(0.018)	(0.014)	(0.073)	(0.021)	(0.022)	(0.084)	(0.324)	(0.039)	(0.002)	(0.137)	(0.024)
0.30	0.093***	−0.286***	0.217**	−0.065***	−0.079***	−0.196**	0.403**	0.113***	−0.001	−0.409***	−0.102***
	(0.018)	(0.014)	(0.090)	(0.021)	(0.022)	(0.080)	(0.189)	(0.030)	(0.002)	(0.137)	(0.032)
0.40	0.135***	−0.109***	0.186**	−0.063***	−0.158***	−0.215**	0.161***	0.157***	−0.001	−0.392***	−0.051
	(0.019)	(0.015)	(0.080)	(0.021)	(0.022)	(0.086)	(0.040)	(0.042)	(0.001)	(0.134)	0.110
0.50	0.148***	−0.119***	0.154**	−0.098***	−0.158***	−0.229**	0.283***	0.509***	−0.001	−0.358**	−0.051
	(0.020)	(0.016)	(0.055)	(0.021)	(0.044)	(0.101)	(0.045)	(0.168)	(0.002)	(0.178)	0.146
0.60	0.032	−0.032**	0.102**	−0.089***	−0.158***	−0.270**	0.267***	0.763***	−0.002	−0.119	−0.034
	(0.019)	(0.015)	(0.041)	(0.021)	(0.022)	(0.096)	(0.066)	(0.189)	(0.002)	(0.200)	0.164
0.70	0.021	−0.016	0.080***	−0.091***	−0.950***	−0.230**	0.227***	0.959***	−0.002	−0.017	−0.017
	(0.019)	(0.015)	(0.021)	(0.021)	(0.103)	(0.095)	(0.045)	(0.189)	(0.002)	(0.200)	0.164
0.80	0.042**	−0.145***	0.070***	−0.087***	−0.054***	−0.194**	0.160***	1.077***	−0.001	−0.136	−0.275***
	(0.021)	(0.016)	(0.021)	(0.026)	(0.005)	(0.095)	(0.051)	(0.294)	(0.004)	(0.312)	0.074
0.90	0.074***	−0.174***	0.098***	−0.072***	−0.052***	−0.172**	0.201***	1.390***	−0.001	−0.222	−0.375***
	(0.023)	(0.019)	(0.021)	(0.013)	(0.005)	(0.086)	(0.051)	(0.440)	(0.006)	(0.468)	0.111
0.95	0.040*	−0.194***	0.148**	−0.079***	−0.048***	−0.192**	0.257***	2.780***	−0.001	−0.222	−0.580***
	(0.023)	(0.018)	(0.064)	(0.024)	(0.005)	(0.094)	(0.054)	(0.524)	(0.007)	(0.557)	0.132

Note: The table reports the quantile estimation results. The *SEs* are between brackets. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.
Source: Author Estimations.

TABLE 4 Results of the Wald Test for the constancy of parameters

Variables	Wald-statistics [*p*-value]
ρ^*	17.535***[.000]
β_{GDP}	47.371***[.000]
$\beta_{GDP}{}^2$	27.113***[.000]
β_{INV}	8.48***[.000]
β_{REN}	6.481***[.000]
φ_1	11.420***[.000]
δ_o^{GDP}	4.082***[.000]
$\vartheta_o^{GDP^2}$	0.194[.992]
ω_o^{INV}	8.402***[.000]
λ_o^{REN}	15.433***[.000]

Source: Authors Estimation.

4 | DATA ANALYSIS AND RESULTS

Yearly data on the variables under research were extracted from the World Development Indicators' databank (WDI) from 1990 to 2018. Moreover, the data are transformed to quarterly data utilizing the match-sum method, as done by Godil, Sharif, Agha & Jermsittiparser, (2020) and Shahbaz et al., (2018). GDP/capita, the number of registered patents, energy in kg of oil/capita, and CO_2_EMS metric tons per capita were utilized to measure ECO_GRW, TEC_INV, REN_EN, and CO_2_EMS, respectively. Table 1 depicts the descriptive statistics of the variables that are selected for this study, that is, EC_GRO, TEC_INV, and REN_EN and TCO_2_EMS concerning China. All the means have a positive sign. The mean for TCO_2_EMS is found to be 7.291 with a range of 4.877 as a minimum and 9.256 as a maximum value. The mean of ECO_GRW is 3,256.010 with the minimum and maximum values of 729.161 and 7,752.560, respectively. The mean of TEC_INV is 29,9,431.3 with 5,832 and 1,393,815 as minimum and maximum values, respectively. The mean of REN is found to be 21.793 with 11.696 as a minimum and 34.084 as maximum values. Furthermore, the result of the Jarque-Bera test describes that TCO_2, INV, REN, and ECO_GRW are not normally distributed at a 1% significance level, which shows that, through the QARDL model, further analysis can be done.

Table 2 shows the outcomes of the unit root test. ZA and ADF tests were utilized for this. The outcomes of these tests indicate the stationary feature of the data. Additionally, the ZA unit root test also accounts for the structural break. However, in this research, all the variables are not stationary at level, that is, I (0) but are stationary at I (1), that is, at first difference.

Table 3 depicts the outcome of the QARDL model estimation for China. The ρ parameter depicts a significant link with a negative sign at all quantiles except for 0.70 (i.e., not significant). It shows the parameter dependency. Furthermore, the results indicate that the long-term nexus between the dependent variable TCO_2_EMS and independent variables (EC_GRO, TEC_INV, and REN_EN) is represented by β. The results of GDP show that it is highly significant and positive at all quantiles ranges from 0.05 to 0.95. These outcomes are in harmony with earlier researches such as (Ben Jebli & Ben Youssef, 2015; Chandran, et, al., 2013; Ozcan, 2013). Whereas, GDP^2 is highly significant and negative at all quantiles except for 0.05.

TEC_INV is highly significant and negative at all quantiles, that is, 0.05–0.95. According to these results, an increase in technology innovation will decrease TCO_2_EMS in China. These results are aligned with the previous research studies such as (Long et al., 2018; Samargandi, 2017; Yii & Geetha, 2017). Considering the technological innovation role in sustainability, Wang et al. (2020) explicated that technological innovation can play a domineering role intended for promoting a green economy which in turn helps in attaining sustainability through improving the utilization of resource efficiency effect in conserving energy which fallouts in the reduction of CO_2 emission. Technological innovation is primarily viewed as an important component for the formulation of policies link to environmental protection that can help in the reduction of CO_2 emission ensuing in improving the quality of the environment (Khan et al., 2020). Besides, the adoption of energy-efficient technologies can help in creating a sustainable environment (Khan et al., 2020c; Cheng, Awan, Ahmad, & Tan, 2020).

REN_EN is negative and significant at all the quantiles except for 0.10. This result depicts that at low quantile, that is, at 0.10, REN_EN has no impact on TCO_2_EMS whereas, at all the other quantiles ranges from 0.15 to 0.95, an increase in REN_EN will decrease the TCO_2_EMS in China. This result is consistent with numerous studies such as (Al Mulali & Ozturk, 2016; Shafiei & Salim, 2014; Bolük & Mert, 2015). Additionally, efficient use of energy due to the implementation of technological innovation results in mitigating the emission of CO_2 (Khan & Zhang 2020; Razzaq et al., 2020).

Likewise, the short-term dynamics indicate that the current TCO_2_EMS changes are significantly and positively influenced from low to high quantiles, that is, from 0.05 to 0.95 by their previous levels in China. The past and prevailing changes in GDP influence the prevailing and past variations positively and significantly in TCO_2_EMS at all quantiles, whereas previous and recent changes in GDP^2 significantly and negatively influence the former and present variations in TCO_2_EMS at low quantiles ranges from 0.05 to 0.10. The recent and prior variations in TEC_INV negatively and significantly affect the prior and present changes in TCO_2_EMS at low to moderate quantile, that is, from 0.05 to 0.50. Additionally, the previous and current changes in REN_EN significantly and negatively influence the variations in TCO_2_EMS at low quantiles ranges from 0.05 to 0.30 and at high quantiles range from 0.80 to 0.95. Hence, the overall results of the QARDL model propose that GDP, TEC_INV, and REN_EN are either positive or negative factors determining TCO_2_EMS in the long run along with the short run with respect to China.

Table 4 depicts the Wald test findings of parameter dependency for the short- and long-run parameters. Additionally, in the long- and short-run parameters, the Wald test also examines the nonlinearities for the evaluation of locational asymmetries (Cho et al. 2015). Overall for ρ, the null hypothesis is not accepted in this model. Furthermore, the results of this study depict that in the long-run parameters, the Wald test rejects the null hypothesis for all variables such as GDP,

TABLE 5 Granger Causality in Quantile Test Results

Quantiles	$\Delta TCO2_t \downarrow \Delta GDP_t$	$\Delta GDP_t \downarrow \Delta TCO2_t$	$\Delta TOC2_t \downarrow \Delta GDP^2_t$	$\Delta GDP^2_t \downarrow \Delta TCO2_t$	$\Delta TCO2_t \downarrow \Delta INV_t$	$\Delta INV_t \downarrow \Delta TCO2_t$	$\Delta TCO2_t \downarrow \Delta REN_t$	$\Delta REN_t \downarrow \Delta TCO2_t$
[0.05–0.95]	0.372	0.000	0.938	0.000	0.000	0.000	0.000	0.000
0.05	0.138	0.000	0.275	0.000	0.000	0.000	0.000	0.000
0.10	0.185	0.000	0.313	0.000	0.000	0.000	0.000	0.000
0.20	0.205	0.000	0.399	0.000	0.000	0.000	0.000	0.000
0.30	0.285	0.000	0.461	0.000	0.000	0.000	0.000	0.000
0.40	0.371	0.000	0.538	0.000	0.000	0.000	0.000	0.000
0.50	0.623	0.000	0.582	0.000	0.000	0.000	0.000	0.000
0.60	0.591	0.000	0.772	0.000	0.000	0.000	0.000	0.000
0.70	0.471	0.000	0.826	0.000	0.000	0.000	0.000	0.000
0.80	0.303	0.000	0.681	0.000	0.000	0.000	0.000	0.000
0.90	0.211	0.000	0.538	0.000	0.000	0.000	0.000	0.000
0.95	0.184	0.000	0.381	0.000	0.000	0.000	0.000	0.000

Note: This table presents the *p*-value of estimated coefficients of the Granger causality test by quantiles. *p*-values associated with the *F*-test values are reported.
Source: Author Estimation.

TEC_INV, and REN_EN. However, in the short-run parameters, the Wald test rejects the null hypothesis for all the variables except GDP^2, which indicates that the variables like GDP, TEC_INV, and REN_EN depict the nonlinear and asymmetric nexus, whereas, GDP^2 is insignificant that is, Wald test failed to reject the null hypothesis and shows linear and symmetric nexus in the short-run dynamics of the Wald test.

Table 5 shows the results of the Granger causality test. It indicates the causality between the two variables at different quantiles. The outcomes depict that a bidirectional causal association exists among TEC_INV, REN_EN, and TCO_2_ EMS, that is, which runs from TEC_INV to TCO_2_ EMS and REN_EN to TCO_2_EMS, though, a unidirectional nexus was found between GDP, GDP^2, and TCO_2_EMS which shows that TCO_2_EMS occurs due to GDP but the vice versa situation, that is, which runs from TCO_2_EMS to GDP and TCO_2_EMS to GDP^2 is absent.

5 | CONCLUSION AND POLICY RECOMMENDATIONS

In the preceding studies, numerous scholars have analyzed the causality relationship amid different variables and TCO_2_EMS in China, but the link among the variables used in this study has not been explored previously with the help of QARDL methodology. This investigation involves variables like GDP, TEC_INV, and REN_EN to gauge TCO_2_EMS in China. The annual time-series data from 1990 to 2018 were investigated in this study. The QARDL approach was used to explain the long- and short-run connection between the GDP, REN_EN, and TEC_INV (independent variables) and TCO_2_EMS (dependent variable).

The aftermaths of QARDL reveal that GDP, TEC_INV, and REN_EN significantly influence TCO_2_EMS in China. TEC_INV and REN_EN have a negative impact on TCO_2_EMS. In TEC_INV and REN_EN, this nexus is present at all the quantiles, that is, 0.05–0.95, except for 0.10 in the case of REN_EN. It shows that due to the upsurge in TEC_INV and REN_EN in the country, the TCO_2_EMS is likely to decrease. However, GDP has a positive impact on TCO_2_EMS. Whereas, in the case of GDP^2, it is negatively significant at all the intensities except for 0.05. Moreover, all the null hypotheses were rejected in the long-run parameter, while in the short-run parameter, all the null hypotheses were rejected except GDP^2 in which the Wald test failed to reject the null hypothesis.

Furthermore, the outcomes of this research suggest that the variables that are used in this research are the possible factors determining TCO_2_EMS. Keeping the results in view, the policymakers of China are required to implement measures to lessen TCO_2_EMS at different levels of ECO_GRW. Moreover, it is said that TCO_2_EMS and EN_CON will keep on increasing with time, as Yin et al. (2015) found that TCO_2_EMS can reach the peak in 2060, 2065, and 2080 and then will gradually decrease by 73, 44, and 23%, in 2095 when matched with the reference set with the environment compelling target as 2.6, 4.5, and 6.0 W/m^2, respectively.

Likewise, the government of China should improve its transportation system and should bring innovation in its transportation system by introducing nonpolluting and hybrid cars. China should encourage its people for innovations of electrified cars and railway system to minimize the emission of CO_2 in the transport sector. Moreover, on one hand, the government of China should hasten the use of biofuel in road transport, and on the other hand, waterway and railway rail transport should be further developed. Furthermore, alternative carbon policies can also help in minimizing the sector's CO_2_EMS.

In high CO_2_EMS countries, the utilization of REN_EN could potentially reduce CO_2_EMS, thereby to satisfy energy needs; they must increase the share of REN_EN. Besides, transforming the approach of ECO_GRW is beneficial in moving from nonrenewable to REN_EN sources to satisfy energy needs and efficiently minimize CO_2_EMS. Therefore, it is crucial for the global society to adopt climate change-related policies, mainly for key sectors of CO_2_EMS emissions, such as the transport industry to reduce energy consumption and, consequently, CO_2_EMS from fossil fuels (Khan et al., 2019a; Khan et al., 2021; Godil, Sharif, Afshan, Yousuf & Khan, 2020).

Similarly, high CO_2_EMS nations can upsurge FDI to reduce environmental degradation, whereas low CO_2_EMS countries should first determine the FDI's environmental effect before inviting foreign stakeholders into the state. The reduction in CO_2_EMS can also be achieved through investment in technology innovation i.e. by the import of new technologies. Innovation at the technological level helps in the utilization of a lower amount of energy that might result in producing the output at the same level (Santra, 2017), thus, if countries pursue technological innovation in terms of green technology it can help the firms to improve their efficiency in terms of energy usage. Therefore, technology innovation could lead to lower cost of REN_EN consumption and enhanced energy efficiency. From the aforementioned empirical review, it can be deduced that innovation boosts the choices to manufacture and consume to mitigate the unfavorable influence of emissions from all means on the environment.

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