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Understanding the importance of sustainable ecological innovation in reducing carbon emissions: investigating the green energy demand, financial development, natural resource management, industrialisation and urbanisation channels

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ABSTRACT

Humanity is in more danger from escalating greenhouse gas (G.H.G.) emissions, making the world warmer. The study examined the relationship between China's environmental technologies, ecological innovation, and carbon emissions using time-series data from 1975 to 2020. The N.A.R.D.L. approach is used to examine the cointegration of variables in the short and long run. In the short run, environmental technologies, industrialisation (I.N.D.), positive shocks to natural resource depletion (N.R.D.), negative shocks to renewable energy (R.E.) use, and technical advancements affect carbon emissions. On the other hand, positive shocks to environmental technologies and financial development (F.D.), negative shocks to N.R.D., R.E. consumption (E.C.), and technical innovation all have a long-term effect on carbon emissions. Granger causality was used to examine the causal link between variables. According to the findings, environmental technologies, F.D., technical innovation, N.R.D., and economic growth (E.G.) cause carbon emissions. The impulse response function revealed an inverse link between asymmetric environmental technology and carbon emissions. In contrast, F.D. and N.R.D. directly affect environmental degradation over time. The outcome of the variance decomposition revealed that negative shocks of F.D. would likely exert greater pressure on achieving sustainable environmental agenda. Investment in environmental technology, F.D.,

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technological innovation and R.E. should be encouraged by the Chinese government to achieve sustainable prosperity.

1. Introduction

Environmental degradation and global warming are two of the world's most challenging problems. The environment has been adversely impacted by greenhouse gas (G.H.G.) emissions, particularly carbon emissions, which have resulted in rising temperatures, harsh weather conditions, rising sea levels and melting polar ice caps (Khan, Saleem et al., 2022). Human activities such as the combustion of fossil fuels, extensive forest depletion, expanding industrial activities, and non-R.E. sources all contribute to the increase in G.H.G. emissions, such as CO_2, CH_4, SF_6 and N_2O, resulting in global warming (Usman et al., 2021). The ecosystem is also threatened by human activities; basic human needs such as clean drinking water, pollution-free air, clean food and energy are not being met. The increasing demand for these essentials exacerbates ecological stress, accelerates natural resource depletion (N.R.D.), and promotes emission and deception in the environmental and economic systems (Yang & Khan, 2022). Over the last few decades, governments around the globe have struggled to address these climatic challenges and minimising environmental concerns is one of their primary objectives which has garnered significant policy attention. It is critical to achieving sustainable growth while protecting the environment and leaving our planet in the best possible condition for future generations (Ulucak et al., 2020).

Energy consumption (E.C.) has increased significantly over the previous several decades due to rapid industrialisation (I.N.D.), and the E.C. is often non-renewable. Additionally, when N.R.D. accelerates, the environment becomes increasingly contaminated. People's awareness of global warming has increased in recent years, and many countries have shifted toward R.E. (Rashid Khan et al., 2021). Increased industry and financial development (F.D.) have also increased E.C. and emissions (Kihombo et al., 2022; Kirikkaleli & Adebayo, 2021). F.D. and globalisation are thus critical variables affecting the quality of the environment and they play a critical role in enhancing environmental quality (Tahir et al., 2021). F.D. is a critical indicator of a sustainable environment since developed countries benefit from a safer and cleaner environment than less developed economies due to their more developed financial system (Usman et al., 2021; Yang et al., 2021).

F.D. encourages investment in cleaner technology and research and development that supplants polluting manufacturing processes. Every country's objective is to achieve sustainable growth and environmental protection, and F.D. plays a crucial role in accomplishing this goal (Tahir et al., 2021). It is critical for carbon emissions reduction since it enables the industry to acquire modern gear that emits less pollution. Additionally, F.D. enables increased research and development in cleaner technology and contributes to environmental sustainability (Bhutta et al., 2022). By promoting eco-friendly approaches, developed financial systems contribute to a healthy environment. As a stable financial system encourages the use of cleaner technology in energy-intensive businesses, emissions levels can be reduced (Usman, Jahanger et al., 2022; Usman et al., 2021). Research and development are critical components in bringing innovation to technological energy patterns, ensuring a healthy environment, and mitigating carbon emissions (Wang, 2022). Governments and relevant agencies in industrialised countries pay significant sums to further research and development to promote environmentally friendly technology advancements (You et al., 2022). Global population growth increases demand for commodities and the majority of sectors that rely on non-renewable energy (N.R.E.), which contributes to economic development and increases pollution. As a result, research and development are critical in this situation (Shao et al., 2021; Wang & Zhang, 2020). Green innovation is crucial for enhancing environmental quality and reducing pollution by facilitating access to new technology. Additionally, green inventions help reduce carbon emissions, advance environmental sustainability, and boost energy efficiency (Bhutta et al., 2022).

R.E. is an alternative to fossil fuels and is a crucial component of sustainable development. Energy investment is essential for economic and environmental growth. Green innovation in the energy industry is a critical component of emissions reduction and environmental sustainability (Ulucak, 2021). Cleaner technologies are critical for all sectors and energy conservation (Mensah et al., 2019). Green innovation technologies mitigate the negative influence of human activities on environmental quality by promoting energy efficiency and sophisticated technological manufacturing. By reducing carbon emissions, promoting cleaner technologies, and successfully managing waste generated by industry and other human activities, technology may help decrease carbon emissions (Ahmed, 2020; Chu, 2022). Technological advancements stimulate economic development while lowering carbon emissions. As a result, it contributes to environmental sustainability and carbon neutrality (Shao et al., 2021). The energy intensity (E.I.) of economic activity is the quantity of energy needed to create a particular unit of economic activity and is a proxy for technical advancement (Hou et al., 2020; Koyuncu et al., 2021; Qi et al., 2019). Energy is critical for economic growth (E.G.) and fundamental needs fulfillment. On the other hand, increased E.I. degrades the environment if it is based on non-renewable sources. Environmental dangers posed by N.R.E. sources are a point of contention in talks on environmental sustainability. Increased E.I. increased carbon emissions, which jeopardised ecologically favourable human activities (Ulucak & Khan, 2020). E.I. is a critical factor in building a sustainable environment (Khan, Babar et al., 2022). There is a considerable positive correlation between carbon emissions and E.I. (Chu, 2021). Enhancing energy efficiency or lowering E.I. is critical to decreasing carbon emissions (Nasir et al., 2021).

Consumption of R.E. helps prevent environmental contamination and reduces ecological footprints. At the same time, increasing the E.I. of N.R.E. results in an increase in environmental damage (Chu & Le, 2022). E.G. and environmental performance are inextricably linked to research and development. Suppose resources are effectively used for production, green technical advancements in the energy sector, R.E., prudent financial management, and enhanced research and development. In that case, the economy may achieve sustainable E.G. and environmental improvement (Wang, 2022). Additionally, urban population increase and E.I. significantly impact environmental quality (Koyuncu et al., 2021). Thus, sustainable development refers to a country's capacity to manage current living societies' natural resource demands without jeopardising future generations' access to natural resources (Ahmad et al., 2020). The availability of natural resources is another source of economic and social growth. Demand for consumer products rises as the economy grows, while N.R.D. increases to supply the increased demand. This often results in environmental damage, so it is critical to preserve environmental sustainability (Khan, Chenggang et al., 2020; Zafar et al., 2019). The increased pace of N.R.D. is the primary cause of environmental harm. It has been discovered that N.R.D. and environmental degradation have a positive and substantial association with development (Gyamfi, 2022).The availability of natural resources contributes significantly to carbon emissions in the industrial sector (Li et al., 2019). Regional resource-based economies have a substantial impact on I.N.D. and regional development, and however, most of these businesses use energy and produce pollution. As a result of the availability of natural resources, resource prices are low, resulting in excessive and inefficient energy usage (Wang et al., 2019; Yang et al., 2018). China is endowed with natural resources since it has a sizable mining sector, a considerable coal production capacity, and is the world's biggest consumer of fossil fuels (Ahmed, Asghar et al., 2020). Overexploitation of natural resources has been seen to promote financial gain and contribute to environmental deterioration by increasing the strain on natural resources and diminishing biocapacity (Afshan & Yaqoob, 2022).

The study addresses the following research question by examining the critical variables contributing to environmental sustainability, i.e., to what extent does ecological innovation help mitigate carbon emissions? The crucial role of R&D expenditures remains needed for devising green and clean environmental policies. The second research question is: does F.D. contribute to increasing carbon emissions? F.D. has both positive and negative effects on the quality of the environment. The positive effects lead to verifying the pollution halo hypothesis. In contrast, the adverse effects confirmed the pollution haven hypothesis, which is deemed desirable to evaluate its impact on the Chinese economy. The critical role of green technology advancements in mitigating carbon emissions and ensuring a healthy and safe environment is vital for sustainable development. Thus, the third research question is whether China promotes sufficient green technical advances to address pollution? E.I. is a critical factor in building a sustainable environment. This research aims to determine the effect of E.I. on carbon emissions. The fourth question is whether energy use has a beneficial effect on environmental quality? The availability of natural resources is another source of economic and social growth. Hence, the fifth question is how natural resource availability and depletion affect China's carbon emissions, whether they are favorably or negatively connected? The questions have specific policy implications, which need to be formulated through intelligent decisions.

The following research objectives have been set to evaluate sustainable economic policies, i.e.:

1. To analyse the role of sustainable ecological innovation in reducing carbon emissions.

2. To assess the role of F.D., natural resource management and green energy demand in improving environmental quality levels, and
3. To investigate industry-induced, E.G.-induced and urbanisation-induced (U.R.B.) emissions.

This article is organised as follows. It first begins with an introduction. The second section offers a survey of the available literature on the issue. The third section discusses the data and technique used to examine the research questions, followed by a description of the variables. The fourth section discusses the results and findings. Finally, this article presented the conclusion and policy recommendations.

2. Literature review

The E.I. of an economic activity refers to the quantity of energy needed to create a particular unit of economic activity and indicates the degree of technological advancement. Energy is critical for E.G. and meeting fundamental human needs. Pilatowska et al. (2018) added to the literature by examining the asymmetric response of carbon emissions to gross domestic product (G.D.P.) changes using a V.A.R. model with the linear and asymmetric specification for European Union (E.U.) nations. They concluded that certain nations' CO_2 responses to G.D.P. are asymmetric. From E.G. to carbon emissions, asymmetric implications are also shown for Spain and Belgium. The findings indicated that policymakers should enact legislation to safeguard the environment. Mao (2018) used the synthetic control approach to investigate the causal influence of Indonesia's democratic transition on the country's carbon dioxide emissions intensity. The results indicated that democratic transition increases carbon emissions intensity by roughly 25.34%. Instead of alleviating, it exacerbates Indonesia's carbon emissions. It is advocated that accountable entities concentrate their efforts on reducing the effects of democratic transition. Goldemberg (2020) assesses the energy and carbon intensity of a collection of nations from 1990 to 2014, covering lower, medium, upper-middle, and higher-income countries. The data indicate a consistent reduction across all nations. This decline in emissions has been attributed mainly to technological leapfrogging. Additionally, carbon emissions increase faster than energy supply in low- and upper-middle-income nations and the global average but decrease in high- and low-income countries. Zubair et al. (2020), utilising time-series data from 1980 to 2018, explore whether E.G., inbound F.D.I. and trade integration contribute to carbon emissions reduction in Nigeria. They discovered a long-term link between carbon emissions and their potential predictor. Additionally, it is seen that as E.G., capital and F.D.I. increased, carbon emissions decreased throughout the examined period. The findings indicated that Nigeria's empowered entities should encourage cleaner technology while simultaneously protecting the environment for E.G.

Nondo and Kahsai (2020) examined the link between South Africa's per capita E.G., I.N.D., U.R.B., E.I., and carbon emissions from 1970 to 2016. The results established long-term cointegration between variables. According to Granger causality, all factors were bi-directionally associated with carbon emissions except for G.D.P. and

E.I. At the same time, E.G. and E.I. are positively connected in both directions, from E.I. to G.D.P. per capita. Based on the findings, it has been proposed that responsible entities adopt policies to reduce carbon emissions and mitigate the consequences of U.R.B. Zhu et al. (2021) examined the effect of U.R.B. on the E.I. of 38 O.E.C.D. nations using panel data for the period 1990–2015. They discovered a non-linear or inverted U-shaped link between U.R.B. and E.I. using the G.M.M. approach. Additionally, they introduced innovation as a moderating variable and discovered that the more innovation, the more the influence of U.R.B. on E.I. is inhibited. As a result, these selected countries should increase their level of innovation, safeguard the environment, and mitigate the G.H.G. impact. Chu and Le (2022) used time-series data from 1997 to 2015 to analyse the influence of R.E., economic complexity, E.I., and economic policy uncertainty on the environmental quality of G7 nations. The findings indicate that R.E. and economic complexity both contribute to reducing carbon emissions. While the more the E.I., the greater the damage to the environment. On the other hand, economic policy uncertainty limited the influence of energy efficiency, economic complexity, and R.E.. The findings indicated the need to implement appropriate policies to safeguard the environment. The study proposes the following hypotheses based on the literature:

H1: Sustainable technical innovation has the potential to cut carbon emissions.

H2: Green energy helps lessen carbon emissions to achieve a zero-carbon emissions.

Meirun et al. (2021) used yearly data from 1990 to 2018 to study the dynamic influence of green technology innovation on Singapore's carbon emissions and economic development. They used the bootstrap autoregressive distributed lag approach. The findings indicated that green technology innovation has a negative and substantial effect on carbon emissions in both the short- and long-term while having a positive and significant effect on EG. The government is urged to ensure the existence of such an environment that encourages investment in green technology innovation. From 1980 to 2018, Shao et al. (2021) investigated the influence of R.E. and green technology innovation on carbon emissions in the N-11 nations. Using cross-sectional augmented autoregressive distributed delays, we find that R.E. and green technology innovation have a considerable and adverse effect on carbon emissions over the long-term. In contrast, green technology innovation is not substantial enough in the near term to significantly reduce carbon emissions. As a consequence of the findings, it has been proposed that policies promoting R.E. and green technology innovation should be supported. Ope Olabiwonnu et al. (2022) examined the association between the energy sector, hydropower, and carbon dioxide emissions during the pandemic phase. According to their results, E.C. and carbon emissions decreased, resulting in decreased oil and coal costs during the COVID-19 epidemic. It has been argued that accountable entities should prioritise policies that encourage sustainable energy production and carbon reduction to safeguard the environment. Shan et al. (2021) examined the link between R.E., green technology innovation, and carbon emissions in Turkey from 1990 to 2018. They employed the S.T.I.R.P.A.T. model. According to the findings, R.E., green technology innovation, per capita income, population, and carbon emissions are all converging in the long-term. Carbon emissions grow as per capita income, population, and energy use increase. In comparison, the use of R.E. and green technology innovation helps to reduce CO_2 emissions. The findings indicated that measures promoting environmental sustainability via R.E. and green technology innovation should be implemented.

Aeknarajindawat et al. (2020) used time-series data from 1988 to 2017 to examine the link between natural resources, E.G., R.E. and carbon emissions in Malaysia. Economic expansion and N.R.D. harm the environment, whereas R.E. helps offset carbon emissions. Environmental protection should be a priority for policymakers and the government. Hussain et al. (2020) examined the influence of N.R.D. on carbon dioxide emissions and E.C. in 'Belt and Road' nations from 1990 to 2014. The findings indicate that there is a positive correlation between N.R.D. and carbon dioxide emissions, as well as energy use. A 1% rise in resource depletion results in a 0.0286% increase in carbon emissions and a 0.0117% increase in E.C. Additionally, economic expansion, U.R.B., and trade liberalisation all positively and considerably affect carbon emissions. To reduce carbon emissions, it has been argued that we should promote energy efficiency and carbon-efficient technology. Wang, Vo et al. (2020) investigated the effect of economic globalisation on G.H.G. emissions. Additionally, they explored the link between agricultural value addition, F.D., N.R.D. and environmental deterioration. For the G7 nations, statistics from 1996 to 2017 were used. The C.S.-A.R.D.L. .findings indicate a favourable correlation between natural resources, FD, economic globalisation and carbon emissions. At the same time, agricultural value addition contributes to emission reduction. The findings imply that the economy's structure should be shifted toward a greater reliance on R.E. sources. Additional research and development are required in the energy industry and the development of sustainable agriculture. Umar et al. (2020) use time-series data from 1980 to 2017 to assess the cost of economic expansion and natural resource usage in terms of environmental deterioration in China. Natural resource exploitation and economic expansion, according to research, result in increased carbon emissions and deterioration of environmental quality. On the other hand, globalisation has a negative influence on carbon emissions and contributes to environmental quality improvement. Responsible entities must guarantee that their reliance on N.R.E. in China is reduced. Policies should be developed to optimise the utilisation of natural resources. Balsalobre-Lorente et al. (2021) examine the influence of ageing and natural resource exploitation on environmental quality in the top five European nations from 1990 to 2017. The findings support an environmental Kuznets curve theory since an inverted U-shaped connection exists. Economic expansion, globalisation, and natural resource exploitation are all correlated. According to the idea, public–private partnerships are necessary to safeguard the environment. Huang, Sadiq et al. (2021) investigated the impact of F.D., natural resource rent, and U.R.B. on environmental quality in the U.S.A. from 1995 to 2015. The quantile autoregressive distributed lagged model revealed that F.D., natural resource rent, and U.R.B. all degrade environmental quality, increasing environmental pressure in the long-term. Thus, governments must rein in the frightening effects of growing F.D., natural resource development, and U.R.B. to maintain a healthy environment and implement policies. Based on the cited literature, the following hypotheses are as follow:

Table 1. Literature review on sustainable ecological innovation and its potential factors.

Authors	Time period	Results
Wang, Su, et al. (2020)	1998–2017	RE and green investment are significant factors in limiting production-based CO_2 emissions. Further, FD, human capital and environment-related technology are also helpful in limiting carbon output.
Yan et al. (2020)	1997–2015	RE technical innovation considerably influences green productivity when the provincial relative income is a vital turning point. Other than the turning point rise in relative income, green production increases.
Wang and Zhu (2020)	2001–2017	RE technology innovation helps lower carbon emissions, but fossil energy technology innovation is not environmental friendly. Hence, China's government should push the RE innovation technologies to maintain the low carbon emission in the economy.
Ma et al. (2021)	1995–2019	Tertiary sector development and local expansion affect the carbon emission favorably. In contrast, RE consumption, energy investment, R&D spending, and technical innovation lowered carbon dioxide output in China. Results recommended that responsible entities implement emission reduction strategies and encourage RE use.
Sun et al. (2021)	1990–2017	In the long-run economic development and carbon emission are related in an inverted U-shaped connection. Economic forces and solar technology advancements counteract the carbon emission. It has been proposed that the Chinese government promote green technologies and research and development to safeguard the environment.
Liu et al. (2021)	1995–2017	There exists the long term cointegration of green investment and carbon emissions. Investment in green initiatives helps to minimise carbon output in China, and natural resource exploitation, FD and EI boost emissions.
Zahoor et al. (2022)	1970–2016	Results indicated the negative relationship between RE investment, ecological footprint and carbon emission. In comparison, RE investment and economic development are favorably associated. Although industrial value-added, financial development and URB spurred economic development but deteriorated China's environmental quality.
Wang et al. (2022)	2000–2018	FDI has a negative influence on carbon emission. On the other hand, technology positively influences the first three quantiles, whereas it represents a negative impact in the following three quantiles. As FDI and technological innovation improve EI, contributing to the variability in carbon emissions.
Yuan et al. (2022)	2005–2017	Green investment plays a vital role in lowering carbon emissions. However, institutional quality has a negative moderating influence on the link between green investment and carbon emission. Explaining that better institutional quality leads to more green investment, resulting in reduced carbon output.
Zeng et al. (2022)	2001–2019	Despite the green technology innovation rising in China but tits efficiency rate is poor. Moreover, its overall carbon output grows while EI drops. It is evident from data that green technology investment helps significantly to minimise carbon output.

Source: Author's compilation.

H3: E.I. is positively correlated with environmental deterioration and carbon emissions.

H4: F.D. affects environmental quality as the result of the pollution halo effect.

Table 1 shows the recent literature review on sustainable ecological innovation and its potential determinants.

Following an assessment of the available literature, the study proposes the following research hypotheses:

H5: Increased exploitation of natural resources results in environmental damage.

H6: Continued E.G., unsustainable production, and massive U.R.B. jeopardises the natural environment.

Earlier research has shown the association between carbon emissions and other economic factors using a variety of econometric methodologies, as several papers in the literature have indicated. Very few studies have examined the asymmetric link between the factors examined in this research. Thus, by analysing the effects of positive and negative shocks on the Chinese economy, the Non-Linear A.R.D.L. technique will picture the relationship between carbon emissions and other explanatory variables such as F.D., E.I., natural resource availability and green technological innovations.

The literature reviewed here demonstrates the connection between green technology innovation and environmental quality. Most studies demonstrate an inverse link between research and development, green technology investment and carbon emissions. As a result, the more technical advancements occur, the less carbon dioxide is emitted and the more sustainable the ecosystem becomes. As a result of this literature review, the following research hypothesis is advanced:

The above discussion demonstrates that relatively few studies have been conducted to examine the asymmetric link between F.D., technical innovation, E.I., natural resource use and carbon emissions in China (Lahiani, 2020; Ling et al., 2022; Shen et al., 2021). As previously stated, the effect of positive shocks is not identical to that of negative shocks. Thus, this study added to the body of knowledge by evaluating the asymmetry connection between these variables using a non-linear auto-regressive distributed lagged model and identifying evidence for the Chinese economy. Additionally, utilise the impulse response function and variance decomposition to anticipate the future and provide policy recommendations.

The study filled the literature gap(s) based on the earlier cited studies into three different ways. First, the earlier studies assumed that technology innovation is a substitute of environmental technology and they used as potential regressor in their research work (see, Anser et al., 2020, 2021; Nizam et al., 2020; Rashid Khan et al., 2021), however, both the factors are different in their policy implications. White ignoring one factor from another, the policy implications cannot be generalised. Hence, the study used both the factors together in the given research work. Environmental technology is measured by the relative share of R&D expenditures to high-technology exports, while technology innovation captured through total patent applications in a country. Hence, both the factors together in the regression apparatus gives deep insights about their resulting impact on carbon emissions and help to formulate generalised policy implications. Second, a very few studies used green energy sources with the F.D. and I.N.D. in environmental sustainable modeling (Abbasi et al., 2022; Huang et al., 2022; Rehman et al., 2021), while ignoring natural resource factors leading the policy lacuna for green developmental policies. It is obvious that natural resource demand exacerbates for industrial production and gains some economic profit, while it damages the natural environment and future sustainability agenda. Thus, natural resource factor has been added in this study to assess resource curse hypothesis for China. Finally, the study used U.R.B. and E.G. as controlled variables in the study that helps to assess U.R.B. associated emissions and growth driven emissions for a country.

3. Data and methodological framework

The study used CO_2 emissions as dependent variable while environmental technologies, F.D., technological innovations, green energy, N.R.D., U.R.B., I.N.D. and G.D.P. per capita are the response variables. The study uses the annual time series data for Chinese economy for the years of 1975 to 2020. The data is taken from World Development Indicator (W.D.I.) from the site of World Bank (2021). Table 2 shows the list of variables used in given study.

The research focuses on the Chinese economy since it is the world's fastest-expanding economy, accounting for 30% of global growth with steady growth over time (Khan, Khan, & Binh, 2020). Despite its rapid expansion, China remains the world's biggest industrial and exporting nation, contributing considerably to global E.C.. China was the highest emitter of carbon dioxide and used 24% of the world's energy (Lei et al., 2022; Zhang et al., 2017). China's fast E.G. has also been attributed to increasing resource-intensive manufacturing and consumption, which contribute to environmental degradation and have a detrimental effect on the climate (Afshan & Yaqoob, 2022), with scholars calling for more firms to take their social responsibilities (Ma & Bu, 2021) and to develop more platform-based business models (Wang et al., 2022) for a more sustainable growth. China's government is making a concerted effort to moderate its carbon emissions. China's government committed to reducing CO_2 emissions in the Paris climate accord (COP21). Additionally, in its 13th five-year plan the Chinese government has determined to cut carbon intensity by 60 to 65% by 2030 compared to the 2005 level and limit E.C. to less than 5,000 million tons of standard coal (Zhang, Li et al., 2020). Carbon emissions are driven mainly by E.C., and China's rapid development rate is mainly due to E.C. Thus, modifying energy production methods, introducing cleaner technology, fostering F.D., increasing research and development, and minimising U.R.B. and I.N.D. might be feasible for achieving environmental sustainability and E.G. (Khan, Khan, Ali et al., 2020). China's heavy dependence on fossil fuels as an energy source, rapid economic development, and rapid expansion contribute to increased G.H.G. emissions and environmental hazards (Sun et al., 2021).

3.1. Theoretical framework

3.1.1. Pollution control theory

FDI has a twofold effect on the economy; on the one hand, it fosters E.G. by transferring technology, developing new managerial skills, increasing productivity, and improving infrastructural development. In another way, it degrades the quality of the environment. These two opposed salutations generate two distinct hypotheses, dubbed the pollution haven and pollution halo hypotheses. According to the pollution haven theory, pollution-intensive manufacturing activity has been transferred from developed to developing nations through F.D.I. This theory accounts for the direct

Table 2. List of variables.

Variables	Symbol	Measurement	Definition	Expected sign	Theoretical support
Carbon emission	CO_2	CO_2 metric tons per capita	CO_2 emissions are gases produced by human activities, including transportation, manufacturing, heating, and power production.		
Environmental technologies	ET	Share of R&D expenditures on high-technology exports	Human activities degrade the natural environment. Cleaner technologies are used to decrease resource utilization and technology's environmental implications.	Negative	Cleaner technologies helps to improve industrial production and achieve decarbonization agenda (Chin et al., 2020; Alataş, 2022; Khan, Ponce et al., 2022).
Technological innovation	TI	Resident and non-resident patent applications	Technological innovation is an improved product with better technical features. New ideas and technology bring new processes and items to market.	Negative	Sustainable production is possible by introducing new technologies, which helps to mitigate carbon emissions (Abid et al., 2022; Zhang et al., 2022; Zhangqi et al., 2022).
Financial development	FD	FDI inflows	Expansion of the financial system promotes growth and investment. It aims to boost growth, efficiency, and financial market access. Financial development reduces financial system costs.	Positive	Dirty production (pollution haven hypothesis) may increase in the absence of climate financing and ease of environmental regulations (Gao et al., 2022; Haq et al., 2022; Sheraz et al., 2022).
Natural resource depletion	NRD	Adjusted savings: natural resources depletion (% of GNI)	Use surpasses recovery or replacement of natural resources. This term is used in water, mining, agriculture, and fossil fuel. Resources are being depleted faster than they can be replenished.	Positive	Exploitation of natural resources damages clean and green satiability agenda, which may be limit through technological innovations (Gyamfi et al., 2022; Usman, Kousar et al., 2022; Zaman et al., 2017).
Urbanisation	URB	Urban population (% of total population)	Urbanisation is the rural-to-urban movement. Urbanisation diminishes the rural population and develops towns and cities. Cities expanded in population density as most people relocated to live and work.	Positive	The rapid urbanisation exhausts economic and environmental resources that limit through sustainable ecological policies (Musah et al., 2021; Wang et al., 2021; Wang & Wang, 2021).
Renewable energy	RE	Renewable energy consumption (% of total energy)	Renewable energy comes from natural resources, and it lowers energy costs and benefits the environment.	Negative	Switching NRE to RE sources improves environmental quality (Bouyghrissi et al., 2022; Rehman et al., 2022; Zafar et al., 2022).
Industrialisation	IND	Industrialisation value added (% of GDP)	Producing goods from raw ingredients. Machines do the job of humans, and agriculture loses out to industry due to industrialisation.	Positive	Massive urbanisation increase the risk of environmental deterioration that need resilient urban policies to limit it (Ahmed et al., 2022; Elfaki et al., 2022; Mentel et al., 2022).
GDP per capita	GDP	GDP per capita, constant 2015 US$	GDP per capita gauges economic growth. It is a financial statistic that divides gross domestic output by midyear population.	Positive	Continued economic growth supported by unsustainable production and innovation tend to worsen environmental quality (Azam et al., 2021; Cui et al., 2022; Zhong et al., 2022).

Source: Author's compilation.

relationship between F.D.I. and carbon emissions. The pollution halo concept demonstrates that F.D.I. contributes to host nation emission reductions through green technology and new production structures that are not available in the host country's current production processes (Mert & Caglar, 2020).

Numerous rich nations choose to manufacture goods in developing countries, owing to stringent environmental restrictions and cost savings; as environmental restrictions become more stringent in wealthy countries, the cost of manufacturing increases. To avoid the higher costs associated with complying with these rules, most industrialised economies choose to relocate businesses to developing nations with laxer regulations. This phenomenon is often referred to as the pollution haven theory, which states that F.D.I. harms the environmental quality of host nations, hence transforming these developing countries into 'pollution heavens' (Bokpin, 2017; Shofwan & Fong, 2011). The growing economies' trade-off between economic gains and environmental quality (Hanif et al., 2019; He & Yao, 2017). The pollution halo theory is the polar opposite of the pollution haven hypothesis since it asserts a negative association between foreign direct investment and environmental contamination (Balsalobre-Lorente et al., 2019). Foreign direct investment may be beneficial for investing in the energy industry and boosting R.E. sources. These cleaner sources help mitigate the environmental damage produced by the usage of fossil fuels and coal. As a result, green foreign direct investment considerably lowers China's CO_2 emissions (Polloni-Silva et al., 2021; Yi et al., 2022).

3.1.2. Eco-innovation theory

Technological advancements enable counties to embrace new manufacturing practices and minimise their E.I. Additionally, it changes the input mix, which results in a decrease in the energy required per unit of output and a reduction in carbon emissions (Khan, Ali, Kirikkaleli et al., 2020). Environmental innovation, or 'green' technology, tries to mitigate the negative influence of manufacturing processes and products on the natural environment. It encompasses a variety of techniques, such as pollution prevention, waste recycling, carbon capture technologies, hydrogen generation, energy conservation, environmental management and bio-nano technologies (Georgatzi et al., 2020; Razzaq, Sharif et al., 2021). There is a negative correlation between carbon emissions and green research and development. Adopting modern methods and eco-innovations throughout the manufacturing process dramatically reduces the negative influence on environmental quality (Wen et al., 2020). High-tech businesses have the potential to play a significant role in supporting E.G., preserving a sustainable environment and lowering E.C. and carbon emissions. Globalisation compelled practically every country to embrace technological innovation, which has been very beneficial in resolving environmental challenges (Wang, Tang et al., 2020). Eco-innovations help mitigates CO_2 emissions, decrease E.I. and increase the use of R.E. (Ganda, 2019).

3.1.3. Sustainable production and consumption theory

Environmental pollution is one of the most significant impediments to achieving sustainable economic development in the modern period. Higher I.N.D. and U.R.B.

increase employment possibilities and living standards and increase environmental degradation (Pata, 2018). The Paris accord compels countries to pursue sustainable development via low-carbon transformation. The majority of nations have several rules and regulations to decrease carbon emissions and preserve a healthy environment. Manufacturing is a vital sector of the economy and has become a focal point in the context of carbon reduction (Cai et al., 2019; Xu et al., 2018). U.R.B. has accelerated globally over the last few decades, increasing E.I. and contributing to environmental deterioration. Migration from rural to urban regions has two consequences. First, it improves the availability of inexpensive labour in metropolitan areas and hence output. Second, there was a rise in demand for more urban infrastructure. The urban populace places a higher premium on energy-efficient equipment. These are all pathways that can exacerbate environmental deterioration and increase carbon emissions. Rural–urban migration expands industries horizontally and vertically, increases E.C., and degrades the environment (Ahmad, Draz et al., 2021; Zhang, Geng et al., 2020).

3.1.4. Natural resource curse theory

Natural resources and the environment are inextricably linked since the availability of air, water, and soil and natural resource exploitation may have a substantial impact on the quality of the environment in any place. Massive resource exploitation increases G.H.G. and other harmful gas emissions and contributes to N.R.D. and environmental damage (Danish et al., 2019). Depletion of natural resources continually raises energy usage. As 80% of global energy is needed to explore natural resources, natural resource exploration accounts for almost half of world carbon dioxide emissions (Hussain et al., 2020). Natural resources are a gift from nature and are thus freely accessible. Their irrational usage promotes N.R.E. sources, contributes to resource depletion, and results in environmental dangers and ecological difficulties (Ahmad, Khan et al., 2021; Dogru et al., 2020). N.R.D. occurs due to mining for minerals and fossil fuels, soil erosion, deforestation, and excessive consumption, among other factors. All of these behaviours contribute to environmental deterioration, which is why N.R.D. is regarded as the primary cause of global warming (Ali et al., 2021).

3.1.5. Energy efficiency theory

Green technology is the application of technologies to the production and use of energy to reduce G.H.G. emissions and increase energy efficiency. Technological advancements may substantially impact carbon emissions and are critical for CO_2 reduction. Environmental degradation has been mitigated, and emissions lowered in host nations due to technical improvements and environmental protection measures (Khan, Ali, Umar et al., 2020; Sun et al., 2021). The global energy system must be converted into one that is clean and sustainable. Nowadays, technical advancements, or green technology, are critical for mitigating the harmful effect of N.R.E. on the environment and facilitating the transition to a more sustainable economy (Hashmi & Alam, 2019). Green technology has a detrimental effect on carbon emissions. As a nation encourages green technologies, carbon emissions decrease. As a result, green technology advancements play a critical role in enhancing environmental quality (Paramati et al., 2021). Based on the theoretical linkages the study develops the following equation:

$$\ln CO_{2t} = \propto_0 + \propto_1 \ln ET_t + \propto_2 \ln TI_t + \propto_3 \ln FD_t + \propto_4 \ln REC_t + \propto_5 \ln NRD_t + \propto_6 \ln URB_t + \propto_7 \ln IND_t + \propto_8 \ln GDP_t + \mu_t \quad (1)$$

where, CO_2 represents the carbon emissions, *ET* is the symbol for environmental technologies, *TI* represents the technological innovations, *FD* is the F.D., *REC* shows the renewable E.C., *NRD* represents the N.R.D., *URB* is urbanisation, *IND* represents I.N.D. and *GDP* is the per capita gross domestic product.

The study is expecting the following relationships between these variables, i.e.:

$\frac{\partial ln(CO_{2t})}{\partial ln(ET_t)} < 0$ Lower carbon emissions are associated with greater levels of environmental technology.

$\frac{\partial ln(CO_{2t})}{\partial ln(TI_t)} < 0$ The greater the number of technical breakthroughs, the lower the level of carbon emissions.

$\frac{\partial ln(CO_{2t})}{\partial ln(FD_t)} > 0$ The greater the F.D., the more the carbon emissions.

$\frac{\partial ln(CO_{2t})}{\partial ln(REC_t)} < 0$ The higher the utilisation of R.E., the lower the carbon emissions.

$\frac{\partial ln(CO_{2t})}{\partial ln(NRD_t)} > 0$ Carbon emissions grow in direct proportion to the level of N.R.D.

$\frac{\partial ln(CO_{2t})}{\partial ln(URB_t)} > 0$ The concentration of U.R.B. increases the amount of carbon dioxide emitted.

$\frac{\partial ln(CO_{2t})}{\partial ln(IND_t)} > 0$ The greater the level of I.N.D., the greater the level of carbon emissions, and

$\frac{\partial ln(CO_{2t})}{\partial ln(GDP_t)} < 0$ The greater the national income, the lower the carbon emissions.

3.2. Econometric framework

The following sequential step used in building econometric framework of the study, which has been presented in Figure 1 and then detailed descriptions has been added.

Step-I: Unit root test

First, the research evaluated for variable stationarity to see whether the series' statistical features are time changing or not. A stable distribution is considered to be stationary. Consider the model below:

$$y_t = \emptyset y_{t-1} + \varepsilon_t$$

The above equation shows the AR(1) process, the series is said to be stationary if the coefficient of y_{t-1} is less than 1. In other words, if $|\emptyset| < 1$, the variable is stationary at level. If $|\emptyset| = 1$, then the variable contains the unit root process and is non-stationary at level. The third case is when $|\emptyset| > 0$, the series is explosive and divergent, never come to an equilibrium point. Other than these three cases the fourth type of case is also exist when the variable is first differenced stationary. It happens when $y_t - y_{t-1} = \Delta y_t = \varepsilon_t$ in such case random walk is stationary at first difference.

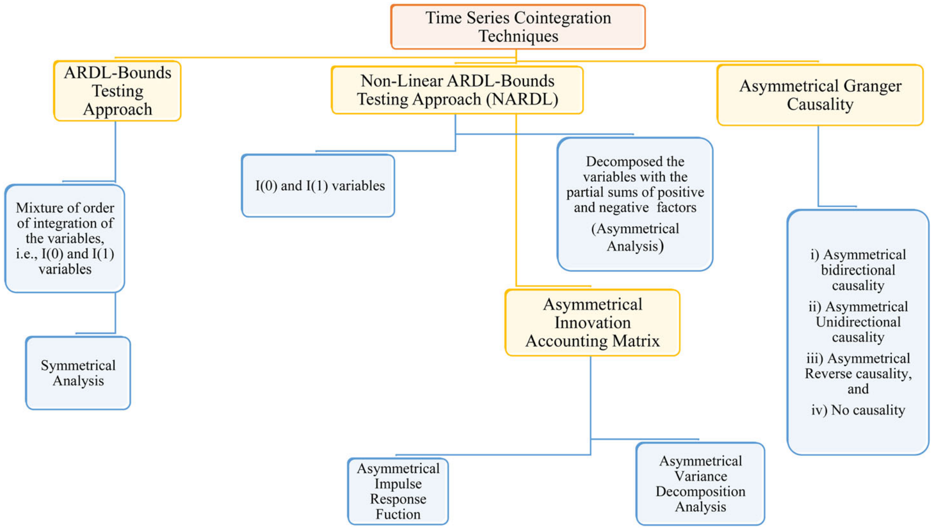

Figure 1. Statistical framework of the study.
Source: Author's construct.

Dickey-Fuller test is a parametric test used to test the null hypothesis of unit root, i.e., the series is non-stationary. It is based on some I.I.D. assumptions that are: (1) error term is normally distributed; (2) residual is white noise; and (3) disturbance term has constant variance. In some cases where the stochastic term is not white noise, the extended form of the Dickey-Fuller test is used, known as the Augmented Dickey-Fuller (A.D.F.) unit root test. The time series variables or model mostly include the problem of autocorrelation or serial correlation; then, we go for the A.D.F. test.

Step-II: A.R.D.L. model

The A.R.D.L. Bounds cointegration investigated the connection between output and response variables. The A.R.D.L. model is used when there are variables with multiple integration orders (I(0) and I(1). Finite data set with unique long-run cointegration. The A.R.D.L. model may be utilised for forecasting and multiplier analysis.

$$\begin{aligned}\Delta CO_{2t} = {} & \boldsymbol{\alpha}_0 + \sum\nolimits_{i=1}^{a} \alpha_{1i}\boldsymbol{\Delta CO_{2t-1}} + \sum\nolimits_{i=1}^{b} \alpha_{2i}\boldsymbol{\Delta ET_t} + \sum\nolimits_{i=1}^{c} \alpha_{3i}\boldsymbol{\Delta TI_t} \\ & + \sum\nolimits_{i=1}^{d} \alpha_{4i}\boldsymbol{\Delta FD_t} \sum\nolimits_{i=1}^{e} \alpha_{5i}\boldsymbol{\Delta REC_t} + \sum\nolimits_{i=1}^{f} \alpha_{6i}\boldsymbol{\Delta NRD_t} + \sum\nolimits_{i=1}^{g} \alpha_{7i}\boldsymbol{\Delta URB_t} \\ & + \sum\nolimits_{i=1}^{i} \alpha_{8i}\boldsymbol{\Delta IND_t} + \sum\nolimits_{i=1}^{j} \alpha_{9i}\boldsymbol{\Delta GDP_t} + \beta_1\boldsymbol{CO_{2t-1}} + \beta_2\boldsymbol{ET_t} + \beta_3\boldsymbol{TI_t} + \beta_4\boldsymbol{FD_t} \\ & + \beta_5\boldsymbol{REC_t} + \beta_6\boldsymbol{NRD_t} + \beta_7\boldsymbol{URB_t} + \beta_8\boldsymbol{IND_t} + \beta_9\boldsymbol{GDP_t} + \boldsymbol{\varepsilon_t}\end{aligned} \quad (2)$$

In the above equation α is the short run and β is the coefficient of long run cointegration among variables. The null hypothesis will be $H_0 : \beta_1 = \beta_2 = \beta_3 = \ldots = \beta_8 = 0$ representing the no long run cointegration exist between variables. An alternative hypothesis is that variables are cointegrated. F-statistics are used to assess hypothesis significance. If the estimated F-test result exceeds the critical value, there is at least one cointegration between variables. This indicates uncertainty and refers to another cointegration approach. The S.B.C. and A.I.C. will be utilised to decide the lag duration. The long-run equation is:

$$\boldsymbol{CO_{2t}} = \beta_0 + \beta_1 \boldsymbol{CO_{2t-1}} + \beta_2 \boldsymbol{ET_t} + \beta_3 \boldsymbol{TI_t} + \beta_4 \boldsymbol{FD_t} + \beta_5 \boldsymbol{REC_t} + \beta_6 \boldsymbol{NRD_t} + \beta_7 \boldsymbol{URB_t} + \beta_8 \boldsymbol{IND_t} + \beta_9 \boldsymbol{GDP_t} + \boldsymbol{\varepsilon_t} \tag{3}$$

If there exists, the long run relationship between these variables the short run equation will be estimated and expected that error correction term will be negative and shows the convergence to equilibrium.

$$\Delta CO_{2t} = \boldsymbol{\alpha_0} + \sum_{i=1}^{a} \alpha_{1i} \boldsymbol{\Delta CO_{2t-1}} + \sum_{i=1}^{b} \alpha_{2i} \boldsymbol{\Delta ET_t} + \sum_{i=1}^{c} \alpha_{3i} \boldsymbol{\Delta TI_t} + \sum_{i=1}^{d} \alpha_{4i} \boldsymbol{\Delta FD_t} + \sum_{i=1}^{e} \alpha_{5i} \boldsymbol{\Delta REC_t} + \sum_{i=1}^{f} \alpha_{6i} \boldsymbol{\Delta NRD_t} + \sum_{i=1}^{g} \alpha_{7i} \boldsymbol{\Delta URB_t} + \sum_{i=1}^{i} \alpha_{8i} \boldsymbol{\Delta IND_t} + \sum_{i=1}^{j} \alpha_{9i} \boldsymbol{\Delta GDP_t} + \boldsymbol{\varepsilon_t} \tag{4}$$

This is the short run equation also known as the Error Correction Mechanism (E.C.M.) equation.

Step-III: N.A.R.D.L. model

The N.A.R.D.L. approach proposed by Shin et al. (2014). Asymmetric responses of variables added in A.R.D.L. model of Pesaran et al. (1999) and Pesaran et al. (2001). It enables variables to be integrated in a different sequence. The N.A.R.D.L. model is used to examine variable asymmetries in the short and long run. N.A.R.D.L. is superior to A.R.D.L. in three ways. This nonlinear A.R.D.L. model is used to determine the cointegration of variables (Liang et al., 2020). It captures the reactions of each response variable's output variable to both negative and positive shocks. N.A.R.D.L. distinguishes between short- and long-term asymmetries. To begin, we specify the following asymmetric long-run equation:

$$CO_{2t} = \propto_0 + \propto_1 ET_t^+ + \propto_2 ET_t^- + \propto_3 TI_t^+ + \propto_4 TI_t^- + \propto_5 FD_t^+ + \propto_6 FD_t^- + \propto_7 REC_t^+ + \propto_8 REC_t^- + \propto_9 NRD_t^+ + \propto_{10} NRD_t^- + \propto_{11} URB_t^+ + \propto_{12} URB_t^- + \propto_{13} IND_t^+ + \propto_{14} IND_t^- + \propto_{15} GDP_t^+ + \propto_{16} GDP_t^- + \mu_t \tag{5}$$

Where, $\propto_0, \propto_1 ... \propto_{16}$ are vector of long run parameters to be estimated.

Based on the above formulation, the long run relation between carbon emission and environmental technologies increases is $\propto_1$ which is expected to be positive. While, $\propto_2$ captures the long run relation between carbon emission and environmental technologies reduction. The other coefficients representing the same relationship with other variables. The N.A.R.D.L. model can be written as:

$$\begin{aligned}\Delta CO_{2t} = {} & \beta_0 + \sum_{k=0}^{p}\beta_1\Delta CO_{2t-k} + \sum_{k=0}^{p}\beta_2\Delta ET^{+}_{t-k} + \sum_{k=0}^{p}\beta_3\Delta ET^{-}_{t-k} + \sum_{k=0}^{p}\beta_4\Delta TI^{+}_{t-k} \\ & + \sum_{k=0}^{p}\beta_5\Delta TI^{-}_{t-k} + \sum_{k=0}^{p}\beta_6\Delta FD^{+}_{t-k} + \sum_{k=0}^{p}\beta_7\Delta FD^{-}_{t-k} + \sum_{k=0}^{p}\beta_8\Delta REC^{+}_{t-k} \\ & + \sum_{k=0}^{p}\beta_9\Delta REC^{-}_{t-k} + \sum_{k=0}^{p}\beta_{10}\Delta NRD^{+}_{t-k} + \sum_{k=0}^{p}\beta_{11}\Delta NRD^{-}_{t-k} + \sum_{k=0}^{p}\beta_{12}\Delta URB^{+}_{t-k} \\ & + \sum_{k=0}^{p}\beta_{13}\Delta URB^{-}_{t-k} + \sum_{k=0}^{p}\beta_{14}\Delta IND^{+}_{t-k} + \sum_{k=0}^{p}\beta_{15}\Delta IND^{-}_{t-k} + \sum_{k=0}^{p}\beta_{16}\Delta GDP^{+}_{t-k} \\ & + \sum_{k=0}^{p}\beta_{17}\Delta GDP^{-}_{t-k} + \gamma_1 CO_{2t-1} + \gamma_2 ET^{+}_{t-1} + \gamma_3 ET^{-}_{t-1} + \gamma_4 TI^{+}_{t-1} + \gamma_5 TI^{-}_{t-1} \\ & + \gamma_6 FD^{+}_{t-1} + \gamma_7 FD^{-}_{t-1} + \gamma_8 REC^{+}_{t-1} + \gamma_9 REC^{-}_{t-1} + \gamma_{10} NRD^{+}_{t-1} + \gamma_{11} NRD^{-}_{t-1} \\ & + \gamma_{12} URB^{+}_{t-1} + \gamma_{13} URB^{-}_{t-1} + \gamma_{14} IND^{+}_{t-1} + \gamma_{15} IND^{-}_{t-1} + \gamma_{16} GDP^{+}_{t-1} \\ & + \gamma_{17} GDP^{-}_{t-1} + \mu_t \end{aligned} \tag{6}$$

The E.C.M. which measures the short-term effects and the consistency of long-term parameter is given as follows:

$$\begin{aligned}\Delta CO_{2t} = {} & \beta_0 + \sum_{k=0}^{p}\beta_1\Delta CO_{2t-k} + \sum_{k=0}^{p}\beta_2\Delta ET^{+}_{t-k} + \sum_{k=0}^{p}\beta_3\Delta ET^{-}_{t-k} + \sum_{k=0}^{p}\beta_4\Delta TI^{+}_{t-k} \\ & + \sum_{k=0}^{p}\beta_5\Delta TI^{-}_{t-k} + \sum_{k=0}^{p}\beta_6\Delta FD^{+}_{t-k} + \sum_{k=0}^{p}\beta_7\Delta FD^{-}_{t-k} + \sum_{k=0}^{p}\beta_8\Delta REC^{+}_{t-k} \\ & + \sum_{k=0}^{p}\beta_9\Delta REC^{-}_{t-k} + \sum_{k=0}^{p}\beta_{10}\Delta NRD^{+}_{t-k} + \sum_{k=0}^{p}\beta_{11}\Delta NRD^{-}_{t-k} + \sum_{k=0}^{p}\beta_{12}\Delta URB^{+}_{t-k} \\ & + \sum_{k=0}^{p}\beta_{13}\Delta URB^{-}_{t-k} + \sum_{k=0}^{p}\beta_{14}\Delta IND^{+}_{t-k} + \sum_{k=0}^{p}\beta_{15}\Delta IND^{-}_{t-k} + \sum_{k=0}^{p}\beta_{16}\Delta GDP^{+}_{t-k} \\ & + \sum_{k=0}^{p}\beta_{17}\Delta GDP^{-}_{t-k} + \pi_0 ECT_{t-1} + \mu_t \end{aligned} \tag{7}$$

The N.A.R.D.L. model follow the given steps. Firstly, the A.R.D.L. approach has been applied irrespective the variables are stationary at level or at first difference. One thing is important to avoid the second order integrated variables, as it invalidates the F-statistics. So, Philips Perron or A.D.F. unit root test to test the stationarity of variables. The null hypothesis of nonlinear A.D.F. test is existence of no cointegrating relationship between variables, such as $\gamma_1 = {\gamma_2}^{+} = {\gamma_3}^{-} = 0$. Alternative hypothesis postulates the existence of long run cointegration. F-statistics are used to check the significance of associations derived from Wald test. If the calculated value of F-statistics is below the lower bound, it means there is no cointegration as the null hypothesis is not rejected. If it crossed the upper bound critical value, then there is evidence of a long-run equilibrium relationship. If it is between the higher and lower bounds represent the uncertainty to reach any decision and referred to some other cointegration technique.

Finally, Wald test is test the following hypothesis, i.e., 0: $\gamma_2{}^{+}{=}\gamma_3{}^{-}$ or $-\gamma_2{}^{+}/\gamma_1{=}{-}\gamma_3{}^{-}/\gamma_1$

Step-IV: Toda-Yamamoto Granger Causality

A dynamic VAR(p) model within the framework of Toda-Yamamoto model is given as follows:

$$\begin{bmatrix} CO_{2t}^{+,-} \\ ET_t^{+,-} \\ TI_t^{+,-} \\ FD_t^{+,-} \\ REC_t^{+,-} \\ NRD_t^{+,-} \\ URB_t^{+,-} \\ IND_t^{+,-} \\ GDP_t^{+,-} \end{bmatrix} = \begin{bmatrix} \alpha \\ \beta \\ \gamma \\ \delta \\ \rho \\ \sigma \\ \tau \\ \emptyset \\ \omega \end{bmatrix} + \sum_{i=1}^{p} \begin{bmatrix} \theta_{11i} & \theta_{12i} & \theta_{13i} & \theta_{14i} & \theta_{15i} & \theta_{16i} & \theta_{17i} & \theta_{18i} & \theta_{19i} \\ \theta_{21i} & \theta_{22i} & \theta_{23i} & \theta_{24i} & \theta_{25i} & \theta_{26i} & \theta_{27i} & \theta_{28i} & \theta_{29i} \\ \theta_{31i} & \theta_{32i} & \theta_{33i} & \theta_{34i} & \theta_{35i} & \theta_{36i} & \theta_{37i} & \theta_{38i} & \theta_{39i} \\ \theta_{41i} & \theta_{42i} & \theta_{43i} & \theta_{44i} & \theta_{45i} & \theta_{46i} & \theta_{47i} & \theta_{48i} & \theta_{49i} \\ \theta_{51i} & \theta_{52i} & \theta_{53i} & \theta_{54i} & \theta_{55i} & \theta_{56i} & \theta_{57i} & \theta_{58i} & \theta_{59i} \\ \theta_{61i} & \theta_{62i} & \theta_{63i} & \theta_{64i} & \theta_{65i} & \theta_{66i} & \theta_{67i} & \theta_{68i} & \theta_{69i} \\ \theta_{71i} & \theta_{72i} & \theta_{73i} & \theta_{74i} & \theta_{75i} & \theta_{76i} & \theta_{77i} & \theta_{78i} & \theta_{79i} \\ \theta_{81i} & \theta_{82i} & \theta_{83i} & \theta_{84i} & \theta_{85i} & \theta_{86i} & \theta_{87i} & \theta_{88i} & \theta_{89i} \\ \theta_{91i} & \theta_{92i} & \theta_{93i} & \theta_{94i} & \theta_{95i} & \theta_{96i} & \theta_{97i} & \theta_{98i} & \theta_{99i} \end{bmatrix} \times \begin{bmatrix} CO_{2t-i} \\ ET_{t-i} \\ TI_{t-i} \\ FD_{t-i} \\ REC_{t-i} \\ NRD_{t-i} \\ URB_{t-i} \\ IND_{t-i} \\ GDP_{t-i} \end{bmatrix}$$

$$+ \sum_{j-p+1}^{d_{\max}} \begin{bmatrix} \varphi_{11j} & \varphi_{12j} & \varphi_{13j} & \varphi_{14j} & \varphi_{15j} & \varphi_{16j} & \varphi_{17j} & \varphi_{18j} & \varphi_{19j} \\ \varphi_{21j} & \varphi_{22j} & \varphi_{23j} & \varphi_{24j} & \varphi_{25j} & \varphi_{26j} & \varphi_{27j} & \varphi_{28j} & \varphi_{29j} \\ \varphi_{31j} & \varphi_{32j} & \varphi_{33j} & \varphi_{34j} & \varphi_{35j} & \varphi_{36j} & \varphi_{37j} & \varphi_{38j} & \varphi_{39j} \\ \varphi_{41j} & \varphi_{42j} & \varphi_{43j} & \varphi_{44j} & \varphi_{45j} & \varphi_{46j} & \varphi_{47j} & \varphi_{48j} & \varphi_{49j} \\ \varphi_{51j} & \varphi_{52j} & \varphi_{53j} & \varphi_{54j} & \varphi_{55j} & \varphi_{56j} & \varphi_{57j} & \varphi_{58j} & \varphi_{59j} \\ \varphi_{61j} & \varphi_{62j} & \varphi_{63j} & \varphi_{64j} & \varphi_{65j} & \varphi_{66j} & \varphi_{67j} & \varphi_{68j} & \varphi_{69j} \\ \varphi_{71j} & \varphi_{72j} & \varphi_{73j} & \varphi_{74j} & \varphi_{75j} & \varphi_{76j} & \varphi_{77j} & \varphi_{78j} & \varphi_{79j} \\ \varphi_{81j} & \varphi_{82j} & \varphi_{83j} & \varphi_{84j} & \varphi_{85j} & \varphi_{86j} & \varphi_{87j} & \varphi_{88j} & \varphi_{89j} \\ \varphi_{91j} & \varphi_{92j} & \varphi_{93j} & \varphi_{94j} & \varphi_{95j} & \varphi_{96j} & \varphi_{97j} & \varphi_{98j} & \varphi_{99j} \end{bmatrix} \times \begin{bmatrix} CO_{2t-j} \\ ET_{t-j} \\ TI_{t-j} \\ FD_{t-j} \\ REC_{t-j} \\ NRD_{t-j} \\ URB_{t-j} \\ IND_{t-j} \\ GDP_{t-j} \end{bmatrix} + \begin{bmatrix} \mu_{1t} \\ \mu_{2t} \\ \mu_{3t} \\ \mu_{4t} \\ \mu_{5t} \\ \mu_{6t} \\ \mu_{7t} \\ \mu_{8t} \\ \mu_{1t} \end{bmatrix} \quad (8)$$

From this equation it is clear that Granger causality from GDP to CO_2, implies that $\theta_{19i} \neq 0$, likewise Granger causality from CO_2 to GDP implies that $\theta_{91i} \neq 0$. After testing the short run and long run parameter estimates, the study used the Granger causality test for obtaining the following postulates:

Postulate I: CO_2 emissions Granger causes the E.T., T.I., F.D., R.E.C., N.R.D., U.R.B., I.N.D. and G.D.P.

Postulate II: E.T., T.I., F.D., R.E.C., N.R.D., U.R.B., I.N.D. and G.D.P. Granger causes CO_2 emissions.

Postulate III: Variables followed the bidirectional relationships between them.

Postulate IV: No causality exists between the variables.

Step V: Innovation Accounting Matrix

According to Sims (1980), I.R.F. measure the dynamic relationship among the variables of interest over time and transforms the V.A.R. model into its vector moving average representations. V.D.A. is mostly used to explain the relative effect of variables and split the total variance related to an outcome into the variance of period, country, industry and other variables of interest. Its distribute the variance of forecast errors in given variable to its own shock and to other variables in the V.A.R. model (Kim & Patel, 2017).

4. Results and discussion

The descriptive statistics for the variables are shown in Table 3. CO_2 emissions continue to average 3.65 metric tons, with a high of 0.86 and a low of 0.09. ET is the proportion of R&D spending on high-technology exports allocated to environmental technology. According to the data, its mean value is roughly 3%, with a standard deviation of 0.01%. The distribution of E.T. is positively skewed. The aggregate of resident and non-resident patent applications is a proxy for T.I. Its average value is around 264936.7 applications from residents and non-residents. F.D.I. inflows are used as a proxy for F.D. According to statistics, it averages 2.33% of G.D.P. and reaches a maximum of 6.18%. R.E.C. accounts for 25.34% of total E.C., with a variance of 9.39% and a negatively skewed distribution. N.R.D. is 3.54% of G.N.I., ranging from 0.59 to 11.54%. Around 36% of the overall population lives in urban areas. This ratio reaches 61% at the highest level and 17% at the lowest, with a standard deviation of 13.89. I.N.D. accounts for 44.47% of G.D.P. on average, including construction, with a negatively skewed distribution.

The correlation matrix in Table 4 indicates a negative association between E.T. and CO_2 emissions, implying that greener technical advancements result in lower carbon emissions in China. The positive correlation between T.I. and CO_2 emissions indicates that as nations improve technologically, they may embrace manufacturing strategies that contribute to environmental damage. The negative correlation between F.D. and CO_2 emissions verifies the presence of the pollution halo hypothesis in the Chinese economy. Carbon emissions are adversely connected with N.R.D., U.R.B., and G.D.P. On the other hand, I.N.D. contributes to environmental deterioration since the two are strongly associated. F.D. and E.T. are intrinsically linked, and I.N.D. and T.I. are strongly associated, leading toward sustainable development.

Before doing the regression analysis, it is necessary to perform a pre-requisite test to ensure that the estimate approach is proper. Stationarity of variables is critical in time series analysis because non-stationarity or the lack of a unit root in variables results in erroneous regression analyses. The A.D.F. and P.P. unit root assesses stationarity of the variables series. Table 5 indicates that T.I. and G.D.P. are level stationary, whereas the other variables are stationary at the first difference level. Given the A.R.D.L. test criteria, no second-order integrated or I(2) variable is identified so that we may continue to the A.R.D.L. and N.A.R.D.L. testing approaches.

Prior to using the A.R.D.L. bound testing technique, it is required to pick an appropriate V.A.R. lag duration. According to Table 6, five of the six distinct lag

Table 3. Descriptive statistics.

Methods	CO_2	ET	TI	FD	REC	NRD	URB	IND	GDP
Mean	3.656	0.034	263496.7	2.336	25.345	3.542	35.829	44.478	4.20E + 12
Median	2.551	0.021	23758	2.375	29.961	2.919	33.375	45.359	2.29E + 12
Maximum	7.352	0.069	1542002	6.186	34.083	11.545	61.428	48.057	1.46E + 13
Minimum	1.250	0.018	0.126	4.49E-05	11.338	0.595	17.400	37.820	3.04E + 11
Std. Dev.	2.239	0.019	442873.2	1.821	9.395	2.787	13.895	2.610	4.40E + 12
Skewness	0.661	0.706	1.785	0.262	−0.466	1.355	0.338	−0.877	1.069
Kurtosis	1.772	1.861	4.822	1.866	1.411	4.392	1.807	2.885	2.829

Source: Author's self-calculation.

Table 4. Correlation analysis.

Variables	CO_2	ET	TI	FD	REC	NRD	URB	IND	GDP
CO_2	1								
ET	−0.734	1							
TI	0.821	−0.481	1						
FD	−0.721	0.176	−0.644	1					
REC	0.791	−0.966	0.539	−0.342	1				
NRD	−0.489	0.761	−0.409	0.028	−0.710	1			
URB	−0.887	0.957	−0.660	0.392	−0.952	0.687	1		
IND	0.207	−0.430	0.268	0.367	0.241	−0.469	−0.413	1	
GDP	−0.735	0.972	−0.492	0.157	−0.912	0.700	0.955	−0.549	1

Source: Author's self-calculation.

length selection criteria indicate that a good lag length for the A.R.D.L. test is three. Thus, the duration of the three lags remains the subject of additional investigation.

The A.R.D.L. test, introduced by Pesaran et al. (2001), is used to assess the cointegration of variables integrated into various orders I(0), I(1), or a combination of both. The A.R.D.L. model used is of order (1, 2, 3, 3, 3, 3, 3, 3, 3). Table 7 summarises the short- and long-term estimates for the A.R.D.L. model. E.T., F.D., G.D.P., and T.I. may all substantially influence CO_2 emissions in the short-term. E.T. and G.D.P. have a significant and detrimental effect on CO_2 emissions. At the same time, G.D.P. and T.I. increased CO_2 emissions. The E.C.M. is negative and substantial, indicating that it is rapidly approaching equilibrium at 1.375% per year. On the other hand, E.T., F.D., G.D.P., I.N.D. and N.R.D. all have a long-term effect on the quality of the environment. E.T., F.D. and G.D.P. all have a substantial and adverse effect on CO_2 emissions, implying that as these variables increase, carbon emissions decrease. In contrast, I.N.D. and N.R.D. directly correlate with CO_2 emissions. The more I.N.D. and greater loss of natural resources jeopardy of the natural environment, which substantiate the industrial and resource curse hypothesis in a country.

The F-Bound test helps confirm a cointegration connection between variables and calculate coefficients. There are three possible scenarios: If the estimated F value is larger than the critical value of the upper limit, we reject the null hypothesis of no cointegration and assert that cointegration exists between variables. If it is smaller than the crucial value of the lower limit, then the null hypothesis is not rejected. If it is between the lower and higher bounds in the third scenario, there will be ambiguity in reaching any choice using another cointegration approach. The bound test estimates in Table 8 are for both A.R.D.L. and N.A.R.D.L. For both estimates, the computed value of F-statistics exceeded the upper bound's critical value, i.e., A.R.D.L.

Table 5. ADF unit root estimates.

	Level		First difference		
Variable	Constant	Constant and trend	Constant	Constant and trend	Decision
CO_2	−1.673	−1.283	−2.968	−2.223	I(1)
	(0.437)	(0.879)	(0.045)	(0.093)	
ET[a]	0.785[a]	−1.752[a]	−4.682[a]	−5.243[a]	I(1)
	(0.992)	(0.710)	(0.000)	(0.000)	
TI	−7.920	−7.858	−7.016	−6.000	I(0)
	(0.000)	(0.000)	(0.000)	(0.000)	
FD	−1.630	−1.181	−5.333	−5.419	I(1)
	(0.459)	(0.902)	(0.000)	(0.000)	
REC	−0.598	−2.585	−3.033	−2.986	I(1)
	(0.860)	(0.288)	(0.039)	(0.147)	
NRD	−1.724	−1.820	−5.693	−5.664	I(1)
	(0.412)	(0.678)	(0.000)	(0.000)	
URB	1.754	−1.326	−3.680	−3.776	I(1)
	(0.999)	(0.868)	(0.007)	(0.027)	
IND	−1.024	−1.402	−4.644	−4.805	I(1)
	(0.736)	(0.846)	(0.000)	(0.001)	

Note: [a]shows Phillips-Perron. Small bracket shows probability value.
Source: Author's self-calculation.

Table 6. VAR lag order selection criteria.

Lag	LogL	LR	FPE	AIC	SC	HQ
0	−53.52384	NA	1.48e-10	2.908086	3.276709	3.044022
1	494.8517	841.6927	5.80e-20	−18.83031	−15.14408	−17.47094
2	641.5968	163.8085	4.54e-21	−21.88822	−14.88438	−19.30542
3	803.6507	113.0609*	5.63e-22*	−25.65817*	−15.33672*	−21.85194*

Note: * shows desirable lag length.
Source: Author's self-calculation.

(7.35 > 3.79) and N.A.R.D.L. (7.56 > 3.17). As a result, it is possible to assert the existence of a long-term cointegration connection.

The N.A.R.D.L. model incorporates the effect of both positive and negative shocks of explanatory variables on the dependent variable. Table 9 summarises the N.A.R.D.L. model's short-run findings. According to the findings, positive shocks in E.T. have a significant and negative association with CO_2 emissions, implying that while the degree of E.T. increases, the level of environmental degradation decreases. Bashir et al. (2020) corroborate the findings. They analysed the link between environmental taxes and carbon emissions and the influence of F.D. and E.T. and discovered that E.T. aids in carbon emission mitigation. Similarly, Cheng et al. (2018), Wang et al. (2019) and Hussain et al. (2022) evaluated the function of E.T. in carbon emission reduction. They concluded that they are critical for environmental quality improvement and emission reduction. As shown by the significant and positive coefficient, I.N.D. has a crucial influence on increasing carbon emissions in the short-term. This means that a 1% rise in I.N.D. results in a 0.3% increase in carbon emissions. Pata (2018) corroborated this finding when he analysed the connection between carbon emissions and I.N.D. in conjunction with other factors and discovered a positive correlation between the two. Ding and Li (2017), Rehman et al. (2021), Opoku and Aluko (2021) and Kahouli et al. (2022) all argued for a positive correlation between I.N.D. and environmental deterioration. As shown by its positive and

Table 7. ARDL short- and long-run estimates.

Variables	Coefficient	Std. Error	t-Statistic	Prob.
D(ET)	−14.890037	2.792244	−5.332642	0.0002
D(ET(−1))	−5.900901	3.118991	−1.891926	0.0851
D(FD)	−0.039237	0.008463	−4.636196	0.0007
D(FD(−1))	0.034068	0.007691	4.429615	0.0010
D(FD(−2))	0.038886	0.010403	3.738067	0.0033
D(GDP)	1.121009	0.360267	3.111607	0.0099
D(GDP(−1))	0.426742	0.776742	0.549399	0.5937
D(GDP(−2))	1.461670	0.442035	3.306684	0.0070
D(IND)	0.006406	0.004698	1.363633	0.1999
D(IND(−1))	−0.021203	0.005663	−3.744115	0.0032
D(IND(−2))	−0.029607	0.007393	−4.004571	0.0021
D(NRD)	−0.001515	0.002625	−0.577086	0.5755
D(NRD(−1))	−0.003646	0.002715	−1.343067	0.2063
D(NRD(−2))	−0.008413	0.003531	−2.382412	0.0363
D(REC)	−0.006303	0.005240	−1.202895	0.2543
D(REC(−1))	−0.005747	0.006685	−0.859636	0.4083
D(REC(−2))	−0.005194	0.004557	−1.139834	0.2786
D(TI)	0.177911	0.078065	2.278994	0.0436
D(TI(−1))	0.330647	0.066968	4.937350	0.0004
D(TI(−2))	−0.161583	0.047424	−3.407233	0.0059
D(URB)	0.020522	0.077827	0.263689	0.7969
D(URB(−1))	−0.488451	0.120827	−4.042568	0.0019
D(URB(−2))	0.154806	0.052353	2.956971	0.0130
CointEq(−1)	−1.375036	0.274298	−5.012928	0.0004
Long Run Coefficients				
Variables	Coefficient	Std. Error	t-Statistic	Prob.
ET	−8.811156	3.691962	−2.386578	0.0361
FD	−0.095750	0.010952	−8.742808	0.0000
GDP	−0.119271	0.063784	−1.869928	0.0883
IND	0.045361	0.009530	4.760036	0.0006
NRD	0.009722	0.004752	2.045863	0.0654
REC	0.005071	0.002796	1.813917	0.0970
TI	−0.016479	0.030405	−0.541987	0.5986
URB	0.010328	0.010483	0.985238	0.3457

Source: Author's self-calculation.

Table 8. Bounds test result.

F-bounds test null hypothesis: no levels relationship									
ARDL bounds test					NARDL bounds test				
Test statistic	Value	Significance level	I(0)	I(1)	Test statistic	Value	Significance level	I(0)	I(1)
F-statistic	7.358	10%	1.66	2.79	F-statistic	7.569	10%	3.19	2.72
K		5%	1.91	3.11	K		5%	3.83	3.22
		2.5%	2.15	3.4			2.5%	4.5	3.88
		1%	2.45	3.79			1%	5.3	3.17

Source: Author's self-calculation.

significant coefficient, positive shocks in N.R.D. also significantly affect carbon emissions. Increased N.R.D. results in increased environmental deterioration, and increases in N.R.D. in a rise of 0.4% in CO_2 emissions. The findings of this investigation corroborate Huang, Xue et al. (2021). They examined the influence of natural resource rent, U.R.B., and F.D. on environmental quality and established a positive correlation between increased carbon emissions and increased N.R.D.. Kwakwa et al. (2020), Gyamfi et al. (2022) and Yu-Ke et al. (2022) studied the link between N.R.D. and carbon emission and found a positive correlation.

Table 9. NARDL short run results.

Variables	Coefficient	Std. Error	t-Statistic	Prob.
D(ET_POS)	−5.867078	2.220445	−2.642298	0.0138
D(ET_NEG)	−15.410759	13.010985	−1.184442	0.2470
D(FD_POS)	−0.006451	0.003918	−1.646371	0.1117
D(FD_NEG)	−0.010252	0.006889	−1.488248	0.1487
D(GDP)	0.001601	0.016651	0.096152	0.9241
D(IND)	0.003798	0.002041	1.860719	0.0741
D(NRD_POS)	0.004714	0.002493	1.891120	0.0698
D(NRD_NEG)	0.003771	0.003125	1.206653	0.2384
D(REC_POS)	−0.003924	0.007188	−0.545965	0.5897
D(REC_NEG)	0.010259	0.005060	2.027392	0.0530
D(TI_POS)	0.661962	0.597016	1.108785	0.2777
D(TI_NEG)	0.078196	0.043046	1.816562	0.0808
D(URB)	0.004518	0.007421	0.608751	0.5480
CointEq(-1)	−0.351876	0.096279	−3.654770	0.0011

Source: Author's self-calculation.

Negative shocks in the use of R.E.C. have a significant effect on CO_2 emissions. The negative coefficient of R.E.C. indicates that a reduction in the use of R.E. results in an increase in CO_2 emissions. Sharif et al. (2019) investigated the dynamic link between R.E. and N.R.E. usage and environmental quality. The findings revealed the negative correlation between R.E. usage and environmental sustainability. Khan, Ali, Kirikkaleli et al. (2020), Dong et al. (2020) and Adebayo et al. (2022) all concur with the study's findings (2020). Another critical factor affecting carbon emissions is T.I.'s negative shock. The TI coefficient demonstrates that a 1% decrease in T.I. results in a 7% rise in China's environmental degradation or carbon emissions. Razzaq, Sharif et al. (2021) corroborate these findings by examining the asymmetric influence of tourism and T.I. in lowering carbon emissions in the Chinese economy. According to the findings, T.I. has the potential to reduce carbon emissions in the long-term drastically. Lyu et al. (2020), Bai et al. (2020) and Mushta et al. (2020) corroborate these findings. The E.C.M. is essential. It has a negative coefficient, indicating that the long-term coefficient will converge to equilibrium at a rate of 0.35% per year.

In Table 10, the long-term findings of the N.A.R.D.L. model are shown. Positive shocks in E.T. have a significant and negative effect on carbon emissions, as shown by their significant probability value and negative coefficient value. These results are comparable to those of Zhang and Li (2022). They evaluated the influence of environmental protection investment and decentralisation on green technology innovation and concluded that it is critical for pollution reduction. These findings are corroborated by Ulucak (2020), Chen et al. (2020) and Yang et al. (2020). Another critical factor affecting carbon emissions is F.D. As seen in Table 8, a positive shock to F.D. has a considerable negative effect on CO_2 emissions, which means that as F.D. progresses, environmental pollution reduces. In comparison, negative shocks to F.D. demonstrate a clear association with carbon emissions; when a country's financial condition deteriorates due to a fall in financial activity, pollution emissions increase. As Kirikkaleli et al. (2022), Zoaka et al. (2022) and Usman, Kousar et al. (2022) have shown, F.D. contributes to carbon emission reduction. The results contradict Khan, Ponce et al. (2022)'s assertion that F.D., among other factors, contributes to increased environmental deterioration in Canada. Negative shocks associated with N.R.D. are also a significant factor. R.E. usage has been shown to affect carbon emissions, both

Table 10. NARDL long run results.

Variables	Coefficient	Std. Error	t-Statistic	Prob.
ET_POS	−16.673687	7.617463	−2.188877	0.0378
ET_NEG	−43.795932	39.520149	−1.108192	0.2779
FD_POS	−0.018334	0.008251	−2.222014	0.0352
FD_NEG	0.040528	0.021060	1.924406	0.0653
GDP	0.004550	0.046999	0.096811	0.9236
IND	0.010793	0.006300	1.713148	0.0986
NRD_POS	0.013397	0.009139	1.465895	0.1547
NRD_NEG	0.047370	0.014379	3.294464	0.0028
REC_POS	0.166851	0.044630	3.738566	0.0009
REC_NEG	−0.014478	0.008136	−1.779510	0.0868
TI_POS	1.881234	1.541218	1.220615	0.2332
TI_NEG	0.222225	0.120537	1.843626	0.0767
URB	0.012839	0.021025	0.610637	0.5467

Source: Author's self-calculation.

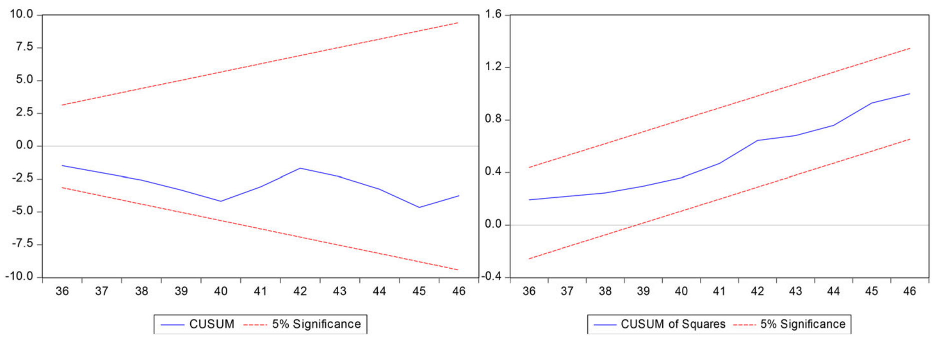

Figure 2. C.U.S.U.M. and C.U.S.U.M. of squares.
Source: Author's illustration.

positively and negatively considerably. According to Bilgili et al. (2016), R.E. use positively and negatively relationship with carbon emissions. Ehigiamusoe and Dogan (2022) confirmed the use of R.E. to reduce carbon emissions. T.I. is another critical factor to consider in the long-term. The negative coefficient of T.I. indicates that a 1% decline in T.I. results in a 0.2% rise in carbon emissions. The findings are consistent with Zhang, Li et al. (2020). They evaluated the influence of T.I. in reducing E.C. and carbon emissions in the Chinese economy and found that T.I. considerably reduces carbon emissions and saves energy. Töbelmann and Wendler (2020), Razzaq, Wang et al. (2021) and Raihan et al. (2022) corroborate these results (2022).

The diagnostic findings for the A.R.D.L. and N.A.R.D.L. models are summarised in Table 11. Both models' error terms are normally distributed, as shown by the probability values of the Jarque-Bera test is larger than 5%, indicating that the null hypothesis of normality is not rejected. According to the stated statistic of the L.M. test, there is no serial association. The R.E.S.E.T. test demonstrates that the models are functionally stable and do not exhibit linear specification bias. The Breusch Pagan Godfrey test indicates that heteroskedasticity is not a concern. In Figure 2, the C.U.S.U.M. and C.U.S.U.M. of squares demonstrate the model's stability. The model is stable because the variable plots do not pass critical boundaries.

After computing the cointegrating coefficients, Table 12 illustrates the Granger causality estimates between variables. According to the results, there is a bidirectional

Table 11. Diagnostic results.

Test type	ARDL	NARDL
Normality test $_{(JB)}$ (p-value)	0.9202(0.631)	0.366(0.832)
LM test (p-value)	1.921(0.201)	0.745(0.4853)
$RESET_{(F)}$ (p-value)	1.318(0.277)	0.1786(0.6761)
Heteroskedasticity $test_{(BPG)}$ (p-value)	0.611(0.858)	1.052(0.4445)
CUSUM and CUSUM Sq & Multiplier graphs	Stable at 95% confidence interval.	

Source: Author's self-calculation.

Table 12. Granger causality estimates.

Variables	CO_2	ET^+	ET^-	TI^+	TI^-	FD^+	FD^-	NRD^+	NRD^-	REC^+	REC^-	URB	IND	GDP
CO_2	–	↔	≠	≠	→	→	≠	≠	≠	≠	→	≠	→	≠
ET^+	↔	–	→	≠	≠	≠	≠	≠	≠	→	→	≠	≠	≠
ET^-	→	≠	–	≠	→	≠	≠	≠	≠	≠	≠	≠	≠	≠
TI^+	≠	≠	≠	–	≠	≠	≠	≠	≠	≠	≠	≠	≠	≠
TI^-	≠	≠	≠	≠	–	≠	≠	≠	≠	≠	≠	≠	≠	≠
FD^+	≠	≠	≠	≠	≠	–	→	≠	→	≠	≠	≠	≠	≠
FD^-	→	≠	≠	→	→	≠	–	→	→	→	→	≠	≠	≠
NRD^+	→	≠	≠	≠	≠	≠	≠	–	≠	≠	↔	≠	≠	↔
NRD^-	→	≠	→	≠	≠	≠	≠	≠	–	≠	≠	≠	↔	≠
REC^+	→	≠	≠	→	→	→	≠	→	≠	–	→	≠	≠	≠
REC^-	≠	≠	≠	≠	≠	≠	≠	↔	→	≠	–	≠	→	≠
URB	≠	≠	≠	≠	≠	≠	≠	→	→	≠	≠	–	→	≠
IND	≠	≠	≠	≠	≠	≠	≠	≠	↔	≠	≠	≠	–	≠
GDP	→	≠	≠	≠	≠	→	≠	↔	≠	≠	→	≠	→	–

Note: ≠ shows no causality, → shows unidirectional causality and ↔ shows bidirectional causality.
Source: Author's self-calculation.

correlation between positive shocks in E.T. and carbon emissions. Negative shocks in E.T., F.D., N.R.D. and G.D.P. Granger cause the CO_2 emissions. N.R.D. Granger causes E.T. There is a unidirectional correlation between R.E. usage and technological advances, which verifies a country's green energy-led technological innovation. Carbon emission Granger causes the negative shocks in T.I., positive shocks in F.D., negative shocks in R.E.C. and I.N.D. Moreover, there is a unidirectional correlation between N.R.D., R.E.C. and G.D.P. N.R.D. and I.N.D. are bidirectional interrelated to support the resource I.N.D. hypothesis.

As seen in Table 13, negative shocks in E.T. have an inverse relationship with carbon dioxide emissions. Positive shocks to E.T. also have an inverse effect on CO_2, implying that E.T. contribute to carbon emission reduction. F.D. is inextricably linked to carbon emissions. Positive shocks to N.R.D. increase emissions in the nation, as illustrated from the first to fourth years, and decrease carbon emissions from the fifth to tenth years. As N.R.D. decreases, carbon emissions likewise decrease in the coming years. China's G.D.P. and I.N.D. will also have a significant positive effect on carbon emissions. Adverse shocks to R.E. use and technological advancements directly affect CO_2 over time.

V.D.A. spreads the variance of prediction errors in a variable between its shock and other variables in a V.A.R. model (Kim & Patel, 2017). It describes how a variable affects both itself and other variables. The findings of the variance decomposition analysis are shown in Table 14. The results reveal that shocks in carbon emission will have a 100% impact on themselves in future years. Among the other factors, the most significant is the negative shock to F.D., which has a variation of 23%. The

Table 13. Impulse response function of CO_2.

Period	CO_2	ET_NEG	ET_POS	FD_NEG	FD_POS	NRD_NEG	NRD_POS	GDP	IND	REC_NEG	REC_POS	TI_NEG	TI_POS	URB
1	0.011242	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0.008594	−0.001881	0.004576	−0.000579	0.004345	0.008728	0.006272	−0.002822	0.005155	0.002873	0.003992	−0.000230	−0.000220	0.000400
3	0.005719	−0.005617	0.007003	0.006385	0.003744	0.009512	0.003621	−0.000698	0.006347	0.000739	3.63E-06	0.000940	−0.000276	−0.000266
4	0.004789	−0.005192	0.009375	0.005787	0.002191	0.009672	0.001473	0.002853	0.006946	0.002316	0.003578	0.002587	0.001165	−0.000860
5	0.000939	−0.010618	0.005169	0.004828	0.001218	0.005769	−0.003619	0.002804	0.004540	0.002020	0.002520	0.001043	0.001895	−0.000707
6	−0.001623	−0.009153	0.008317	−0.003618	0.000538	−0.000847	−0.006363	0.002371	−0.000223	−0.001102	−0.000145	−0.001113	0.000472	0.000297
7	−0.005640	−0.005115	0.006039	−0.008263	7.43E-05	−0.003734	−0.004849	0.000915	−0.002150	−0.001260	0.002004	−0.001991	−0.001122	0.001058
8	−0.008179	0.000554	0.006084	−0.013154	0.001373	−0.008747	−0.003695	−0.002973	−0.003129	−0.001698	0.002989	−0.002528	−0.002276	0.001518
9	−0.008169	0.006206	0.007172	−0.015108	0.000960	−0.007081	−0.000863	−0.005145	−0.002742	−0.001717	0.004901	−0.003055	−0.003080	0.001932
10	−0.007821	0.010408	0.008572	−0.013690	0.000531	−0.003799	0.001754	−0.005298	−0.002359	−0.001359	0.006879	−0.001440	−0.002906	0.001492

Source: Author's self-calculation.

Table 14. Variance decomposition of CO_2.

Period	S.E.	CO_2	ET_NEG	ET_POS	FD_NEG	FD_POS	NRD_NG	NRD_POS	GDP	IND	REC_NEG	REC_POS	TI_NEG	TI_POS	URB
1	0.011242	100	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0.020456	47.85432	0.845998	5.004574	0.080171	4.512602	18.20350	9.400925	1.903503	6.350144	1.972965	3.808733	0.012695	0.011588	0.038282
3	0.027064	31.80386	4.791449	9.553738	5.612607	4.491206	22.75191	7.160121	1.153978	9.127230	1.201690	2.175834	0.127888	0.016991	0.031496
4	0.032979	23.52708	5.705703	14.51569	6.859411	3.466215	23.92385	5.021592	1.525711	10.58280	1.302504	2.642290	0.701591	0.136333	0.089233
5	0.036650	19.11575	13.01424	13.74235	7.289497	2.917059	21.84892	5.040976	1.820642	10.10322	1.358565	2.612399	0.649071	0.377798	0.109514
6	0.039520	16.60835	16.55695	16.24797	7.107011	2.527247	18.83628	6.927611	1.925843	8.692075	1.246132	2.248041	0.637499	0.339183	0.099813
7	0.042183	16.36529	16.00266	16.31066	10.07494	2.218520	17.31641	7.402077	1.737423	7.888859	1.182958	2.198922	0.782279	0.368427	0.150565
8	0.046830	16.32889	12.99850	14.92217	16.06492	1.886018	17.53960	6.628589	1.812686	6.847435	1.091262	2.191501	0.926100	0.535085	0.227247
9	0.052089	15.65726	11.92559	13.95655	21.39680	1.558357	16.02465	5.385116	2.440760	5.811669	0.990681	2.656662	1.092508	0.782132	0.321273
10	0.057070	14.92140	13.26082	13.88256	23.57909	1.306883	13.79265	4.580595	2.895124	5.012385	0.882044	3.665876	0.973757	0.910838	0.335975

Source: Author's self-calculation.

other important variable is a positive shock in E.T., which has a variation of 13.8%, followed by a negative shock in N.R.D. and a positive shock in E.T., which have a variance of 13.79 and 13.2% in the tenth year, respectively. The least influential variable, with a variance of 0.33%, is U.R.B.

5. Conclusions and policy recommendation

Pollution has become a significant impediment to attaining rapid E.G. and sustainable development. As the globe continues on its path of rapid economic expansion, it will encounter climate changes. It contributes to various environmental concerns, including global warming, climate change, increasing sea levels, and deforestation. One of the primary causes of climate change is the G.H.G. emissions that are wreaking havoc on the earth. Climate change has become one of the most critical and hotly debated issues of the twenty-first century, threatening to ruin. It is a worldwide phenomenon due to its critical role in attaining sustainable development. China is the world's fastest-expanding economy and contributes to carbon emissions. China's heavy dependence on fossil fuels as an energy source, rapid economic development, and rapid expansion contribute to increased G.H.G. emissions and environmental hazards.

The purpose of this study is to examine the major factors affecting carbon emissions in China, including E.T., F.D., T.I., R.E.C., N.R.D., U.R.B., I.N.D. and G.D.P., from 1975 to 2020, using various econometric techniques such as A.R.D.L. and N.A.R.D.L. to confirm short-run and long-run cointegration. Toda Yamamoto Granger causality was used to examine the relationship between variables. Additionally, I.R.F. and V.D.A. were used to anticipate the future behaviour of variables. The unit root test was done on all variables, concluding that they are integrated using a mixture of orders I(0) and I(1). The F-bound test confirms long-run cointegration. E.T. have a strong and negative association with carbon emissions in the short-term. I.N.D. and the positive shock associated with N.R.D. contribute to environmental degradation. Reduced use of R.E. and technological advancements also lead to increased carbon emissions. According to the E.C.M., long-run coefficients converge to equilibrium at a rate of 0.35% each year. Over the long-term, a 1% positive shock to E.T. reduced carbon emissions by around 16%. F.D. has an asymmetric effect on carbon emissions since positive shocks result in emission reductions and negative shocks result in emission rises. R.E.C. also exhibits asymmetric behaviour, as technology advancements increase carbon emissions or environmental damage. According to the Toda-Yamamoto Granger causality findings, E.T., F.D., T.I., N.R.D. and G.D.P. Granger causes carbon emissions. The I.R.F. revealed an inverse link between negative shocks in E.T. and carbon emissions, and positive shocks in E.T. have an inverse relationship with CO_2 emissions. F.D. and N.R.D. directly affect environmental degradation. According to the V.D.A., the most influential variable is negative shock in F.D., with a variation of 23%, followed by positive shock in E.T., with a variance of 13.8%, and U.R.B., with a variance of 13.8%.

Due to atmospheric and ecological factors, global health has become a serious concern and challenge. Changes in the global climate and environmental degradation are the greatest obstacles to long-term ecological sustainability. By accumulating carbon pollution on the earth's crust, CO_2 emissions contribute to these problems. Companies in industrialised countries participate in research and innovation but not scaled development, while capital markets opt to fund green procurement projects due to stringent government regulations. Utilising financial markets to increase environmental resilience and mitigate climate change is essential. Whether the capital market's carbon footprint rises as the economy advances, policymakers should encourage investment in ecologically beneficial sectors. As a result of the growth of financial markets and activist organisations, carbon dioxide emissions have increased while the positive impacts of electricity consumption have decreased. Access to the securities market lessens restrictions on equity investments, enhancing their profitability. Promoting sustainable financial innovation is critical for improving the design of financial goods.

Increases in both carbon emissions and E.G. are detrimental to the environment and contribute to the acceleration of climate change. The carbon emissions effects of U.R.B. have shifted as a result of institutional effectiveness. Reduced carbon emissions from a more efficient government can slow global warming and prevent ecological collapse. Alternative energy sources, controlled U.R.B., and flexible trade policies are all viable options for sustainable economic expansion. Reduced E.C. and pollution from U.R.B. are possible with the government's help and the promotion of bioenergy. Chinese authorities should prioritise accelerating sustainable U.R.B. and strengthening community infrastructure to allow rapid urban expansion and take advantage of cluster effects and scale economies. Incentives are necessary to hasten the adoption of alternative energy sources by households and enterprises. Credits, rebates, and other incentives for municipalities to construct R.E. infrastructure might be used for this purpose. Increased government spending on energy R&D will spur creative thinking.

The importance of preserving the long-term viability of the environment on a global scale is brought into sharper focus by challenges such as rising temperatures. Innovation is continuously required to keep an economy in sustainable condition. Without the advancement of technology, neither the growth of the economy nor the conservation of the environment is conceivable. Subsidisation and other forms of financial incentive are required to spur the development of eco-friendly technologies. Since carbon emissions may have repercussions in other parts of the world, creating a regional linking structure for cutting emissions and a framework for managing emissions across regions is essential. The advent of eco-friendly energy and technology may hasten the transition to R.E. sources, spread environmentally responsible activities, and speed up sustainable development. China has to prioritise R.E. and other eco-friendly technology.

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Conflicts of interest

We declare that we have no conflicts of interest to this work.

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