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Towards 2030

Sustainable development goal 9: Industry, innovation and infrastructure. A communication perspective

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Towards 2030: Sustainable development goal 9: Industry, innovation and infrastructure. A communication perspective

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Editorial: Towards 2030: sustainable development goal 9: industry, innovation and infrastructure. A communication perspective

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Editorial on the Research Topic
Towards 2030: sustainable development goal 9: industry, innovation and infrastructure. A communication perspective

In order to achieve UN Sustainable Development Goals by 2030, industrialization needs to be built on a solid and sustainable foundation that seeks an inclusive and innovative approach. The importance of innovation and research in solving fundamental social, economic, and environmental issues has grown. Efforts have emphasized on building new, eco-friendly infrastructure, while retrofitting or reconfiguring current infrastructure systems and utilizing the potential of smart technology, in order to significantly reduce adverse environmental effects and disaster risks that better utilize natural resources on a global scale and enhance community resilience and inclusion.

This collection of research papers brings a human communication perspective to rethink issues related to sustainable development, community resilience and innovation responding to the challenges and complexities of industrial and societal development in the wake of the COVID-19 pandemic. It embodies a wholistic and integrative approach to examine those core pillars of the UN sustainable development goals including people, planet, property, peace and partnership. Balancing the social, economic and environmental dimensions of sustainable development, it not only invites intellectual dialogues to frame and interpret the goal from a conceptual perspective, but also enquires into the strategies and approaches adapting to specific geographical and societal contexts, promoting inclusive industrialization, and involvement of a wide variety of stakeholders and communities. This Research Topic contains eight published peer-reviewed research papers. These studies revealed interplays and dynamic mechanisms among building sustainable infrastructure, innovative development and inclusive industrialization, looking into a grand landscape of emerging markets, including ASEAN countries, Latin American countries and China. Green finance, digital economy, and innovation culture and capacity are highlighted as main themes in this collection of research papers.

Among those studies, four articles conceptualized and studied green finance and its impact on energy efficiency and environment sustainability in a variety of social and economic contexts. For instance, a research group studied green funding, energy efficiency, and CO2 emissions in G7 countries (Fang et al.). Results revealed that green financing is the most effective financial strategy for reducing CO2 emissions. Another study evaluated the impact of green finance and financial development on ASEAN economies' environmental sustainability (Fu and Irfan). Green finance was also explored with data collected from 33 Latin American countries, with an emphasis on the disparities in the effects of green finance, renewable energy (RE), and energy efficiency (EE) on energy poverty (Hou et al.).

Four other studies captured and contextualized "innovation" in a unique economic and societal context of China, diving deeply into the developing trends of business models and industrialization in the last couple of decades. For instance, researchers have conceptualized "digital economy" by investigating its impact on entrepreneurship activities in rural tourism in China, and developed the "Rural Digital Economy index" which could be further testified and expanded to other emerging economies (Tang et al.). Another study discussed green innovation culture as a driving force in Chinese small and medium sized enterprises (SMEs), and examined its impact on market innovation, product innovation and market performance through SEM analysis (Wei et al.). Researchers also examined the mechanism among international technology spillover, institutional quality and green innovation capability (Wang et al.). Findings highlighted the positive effect of international technology spillover on green innovation capability, and emphasized the importance of creating institutional environment to support international technology spillover, while opening up to the outside world and capitalizing on the spillover effect of international technology (Wang et al.). Lastly, the roles of technological innovation, financial development, renewable energy investment, population age, and the economic complexity index in China's environmental sustainability were investigated (Dong and Akhtar). Researchers suggested that regional variances need to be considered while designing policies to increase effective energy consumption (Dong and Akhtar).

Studies mentioned have built upon existing scholarly work, offering insights into the vibrant, fast-changing, and complicated business systems and societal environment of China. They also invite further reflections on the dynamic interplays of infrastructure, industrialization, environment sustainability and innovation on a global scale, responding to the call of the UN's ninth Sustainable Development Goal, "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation".

Studies collected in this special edition offer practical and policy implications regarding green financing, environment sustainability, industrialization and innovation. For instance, researchers examined the impact of the "Digital Economy" on rural entrepreneurship and proposed that the Chinese government should focus on improving the innovation environment for rural residents in the future, so that entrepreneurial activities are spontaneously stimulated by market mechanisms (Tang et al.). Another research explored the dynamic relationships among green innovation technology and carbon emission technology, and recommended that policy makers should be aware of the efficiency of labor and capital allocation of different provinces and regions, in order to promote green technology innovation (Du et al.). From a cultural development perspective, a study recommended that Chinese SMEs should prioritize a green innovation culture in order to improve their market performance. Moving from an "energy-intensive economy" to "technology- intensive economy", researchers also suggested that the Chinese government need to reflect on the increases of carbon emission and the current energy consumption pattern, in order to promote energy efficiency through technology innovation and responding to the aging population relating to the energy consumption structure in the society (Dong and Akhtar).

In this Research Topic, studies have turned their focus from developed economies to emerging economies while emphasizing Asian countries, such as China, as well as Latin American countries. Those research findings have provided fresh insights through the use of empirical data collected from those various countries. As these studies were recently conducted and published, they provided insightful explanations of the dynamically evolving and complex landscapes in our societies. In summary, this volume presents significant studies that offer important implications to advance the SGD goal, by reducing carbon emissions while making the industrialization process more sustainable and inclusive and fostering innovation.

We sincerely thank all of the authors who have contributed to this Research Topic, and we look forward to continuing our scholarly conversation on this fascinating topic.

Author contributions

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How Do Green Finance and Energy Efficiency Mitigate Carbon Emissions Without Reducing Economic Growth in G7 Countries?

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Climate change is one of the most serious threats facing the world today. Environmental pollution and depletion of natural resources have been highlighted by the United Nations Sustainable Development Goals (SDGs), paving the way for modern concepts such as sustainable growth to be introduced. Therefore, this research explores the relationship between green finance, energy efficiency, and CO_2 emissions in the G7 countries. The study uses panel data model technique to examine the dependence structure of green finance, energy efficiency, and CO_2 emissions. Moreover, we use DEA to construct an energy efficiency index of G7 countries. A specific interval exists between the values of the energy efficiency indexes. Japan, the United Kingdom, and the United States were named the most energy-efficient countries in the world, based on results obtained for five consecutive years in this category. However, according to the comparative rankings, France and Italy are the most successful of all the G7 members, followed by the United Kingdom and Germany. Our overall findings of the econometric model confirm the negative impact of green finance and energy efficiency on CO_2 emissions; however, this relationship varies across the different quantiles of the two variables. The findings in the study confirm that green finance is the best financial strategy for reducing CO_2 emissions.

Keywords: energy conversion, energy efficiency, green finance, environment protection, financing efficiency

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INTRODUCTION

The burning of fossil fuels, according to environmental scientists, is the primary reason for greenhouse effect (Ahmad et al., 2021; Abbasi et al., 2022). Greenhouse effect is the buildup of heat in the atmosphere (Ali et al., 2021; Hao Y. et al., 2021; Iqbal et al., 2021b). An important consideration in making any decision is a country's economic growth is the amount of energy it uses (Islam et al., 2021; Ahmad et al., 2022; Irfan and Ahmad, 2022; Irfan et al., 2022). Excessive use of energy, on the other hand, leads to atmospheric emissions of CO_2, SO_2, and CH_4 that degrade the environment (Khan I. et al., 2021; Rauf et al., 2021; Nuvvula et al., 2022). To strike a balance between environmental damage and energy security, restrictions imposed by both the economy and the environment have a role (Tanveer et al., 2021; Wu et al., 2021; Wen et al., 2022). Rapidly rising power demand and prices, resource scarcity, and the social and political consequences of global warming have all contributed to a significant increase in energy security (Razzaq et al., 2020, 2021; Shi et al., 2022). Similarly, rapid economic growth is one of many factors driving up global energy consumption, which has in turn created significant environmental concerns around the world (Yang et al., 2020; Irfan et al., 2021b,c; Xiang et al., 2022). To put it another way, G7 countries account for a disproportionate amount of global warming and climate change. A small number of countries have made only the bare minimum effort to reduce global average temperatures, despite their small size (Tang et al., 2022). Many countries lack the financial resources to generate electricity from renewable sources of energy because of their massive economies' ever-increasing demand for energy (Irfan and Ahmad, 2021; Irfan et al., 2021a). Because of this, rising temperatures are impacting the environment in a bad way.

With the glaciers disappearing and the level of sea rising due to climate change, the hands of time seem to be counting down (Irfan et al., 2020; Elavarasan et al., 2022a,b). More and more people are dying as a result of floods, droughts, heat strokes, and other natural disasters (Elavarasan et al., 2021; Yan et al., 2021). Arctic A threefold increase in heat has been observed in Canada, while temperatures have risen by more than two degrees Celsius over the global average (Li et al., 2021; Hou et al., 2022). People's homes are being destroyed, food is becoming scarcer, and ravenous animals such as bears are on the loose because of the melting of the glaciers. A total of 200 people lost their lives in Japan in 2018 due to landslides and floods caused by the country's record-breaking rainfall. Unimaginable heat waves also threatened the region's most vulnerable species. Extreme weather events will become more frequent and more severe as a result of climate change, and the region's energy consumption will more than double from its current level (Jin et al., 2021; Wang and Luo, 2022). Japanese continuing construction of coal-fired power stations is regrettable. Japan's megabanks have spent $186 billion on fossil fuels since the Paris Agreement was signed, showing that the country's approach to climate change and global warming is worrying. It is possible that 143 million people who have been affected by the effects of climate change will seek refuge in developed countries.

G7 recent progress in creating green financial markets and a green financial system has raised some questions about the role of green finance development in promoting green productivity. Green finance has emerged as a key tool in the green economy transformation. This year's total green bond issuance was US$55.8 billion, accounting for 22% of world issues, according to the Climate Bond Initiative (CBI) (Abbas et al., 2020, 2021; Iqbal et al., 2021c; Zeng et al., 2022). Interest in green finance and its impact on economic and environmental sustainability has grown in recent years, as green finance has become more widely available (Zhou et al., 2020; Dmuchowski et al., 2021; Saeed Meo and Karim, 2021; Wang et al., 2022). The impact of green finance development on green productivity research cannot be understated, as it is a major source of green bonds issuance around the world. Using green finance's capital support function to expedite adjustment of the economic structure and enhance the quality of supply-side investments can help stabilize the growth of the economy from a purely economic standpoint. Sustainable economic and environmental development can be achieved by utilizing the "going green" feature to direct businesses green innovation, environmental protection, and corporate social responsibility and environmental performance (Ahukaemere et al., 2020; Yu et al., 2022).

The current study's contributions are summarized as follows: In the first place, we fill a void in academic report by examining the link between green finance, energy efficiency, and environmental degradation. The development of green finance is a significant influencer. Energy efficiency in contrast to the green productivity is typically measured in terms of scale, technology, and structure; this is a common approach to measuring green productivity. As a result, a better understanding of the factors influencing green productivity can be gleaned from the financial as well as the real estate industries. For a clearer picture of the job of green finance in the green economy, we introduce comprehensive low-carbon financial flows and investment in environmentally friendly products and services are just two of the many ways to measure the impact on climate change from a more holistic perspective. In terms of green finance, the use of a multidimensional index could result in a more comprehensive evaluation of its development. Third, we use them to address the potential omission of energy and environmental constraints, a super-SBM model with undesirable output has been developed, in contrast to previous productivity studies that primarily focused on good output.

The rest of the document is organized as follows: To begin, section "Introduction" provides an overview; section "Literature Review" details the data and methodology; section "Methodology and Data" provides an overview of the findings; and section "Results and Discussion" concludes the study.

LITERATURE REVIEW

The Concept of Green Finance

Finance for, on the other hand, climate change adaptation and mitigation are important provided. However, green finance encompasses not only climate finance, but also a wider range of financial services and products that are focused on a wide objective for the environment such as pollution control, conservation of biodiversity, and natural recourses preservation. However, since its inception in 2010, the Green Climate Fund (GCF) has provided financial assistance to developing nations so that they can better prepare for and cope with the effects of climate change (Pan and Chen, 2021; Zhang et al., 2021a). It was also identified that green finance is essential to financing climate change action following the adoption in 2015 of the Paris Agreement and the Sustainable Development Goals (SDGs) and Sendai Framework for Disaster Risk Reduction (DRRR) (Truby et al., 2022). Various public and private financial institutions are a part of this, along with a variety of asset classes such as "green bonds," "green loans," "green funds," "green banks," and "green credits," as well as "climate finance," "environmentalism," "carbon finance," "sustainable finance," and "sustainable bonds (Wang and Dong, 2022)." Green financing is clearly as a climate change mitigation strategy for green buildings strategy in the building sector. GF-in-GBs will be discussed in depth in the sections that follow, as well as suggestions for how it can be applied better in the future in terms of research, policy, and clinical practice (Huang et al., 2021; Latif et al., 2021; Liu et al., 2021; Mohsin et al., 2021).

Green Finance and Environmental Performance

Effects of financial assistance, resource allocation, and technological advancement, and so on are just a few of the ways that green finance can influence environmental performance. The capital support effect shows that it is possible to achieve better environmental performance by using Low-energy, low-pollution, and low-carbon emissions are the goals of green finance while also discouraging high-pollution and high-emission production behavior. According to Srivastava et al. (2021), the creation of a green credit policy in the People's Republic of China affects the financing costs of enterprises. For high-emission and high-pollution businesses, green credit raises the cost of financing, while it lowers the cost of financing for environmentally friendly businesses, according to their empirical findings. van Veelen (2021) examines the macro-mechanistic role of development of green finance and the effects of green finance on the eco-system is examined. According to the researchers, the impact of green finance varies by region on ecological efficiency.

For example, green finance has the ability to increase capital efficiency and redirect the redirection of financial resources from inefficient and polluting operations industries toward more efficient ones, thereby promoting industrial upgrading, optimizing the energy structure of the economy, and improving the quality of life in the surrounding area. On the basis of micro-mechanics discovered, Zhang et al. (2021b) investigate the impact of a green-credit policy on the loan performance of enterprises. Findings suggest that refusal businesses are credible to pay higher interest rates and have a more difficult time securing loan because of this. In order to improve environmental quality at the macroeconomic level, a well-developed financial system can help alleviate financial constraints on environmentally friendly businesses and promote green upgrading.

This innovation effect in technology means that green finance can help companies that are pursuing green technology innovation obtain external credit, thereby reducing energy consumption while simultaneously promoting growth in the green industry and reducing environmental damage and pollution. Toward this end, Khan M. A. et al. (2021) developed a green loan theory that incorporates the interests of businesses, banks, and the government. It is concluded that government subsidies can lower the cost of financing for businesses, increasing the likelihood that they will implement technological innovation. For high-polluting enterprises, Iqbal et al. (2021a) investigate the influence of a green credit policy on green innovation. A statistically significant increase in green patents was found to be a result of the implementation of the "Green Credit Guidelines" in 2012.

METHODOLOGY AND DATA

Energy Efficiency

Both the energy economics and environmental index have The DEA non-parametric frontier approach has been used to build the model, which was first introduced by Lozano and Gutiérrez (2008) and later developed further by Mostafa (2011). Slack-based models are being used broadly in a wide range of energy and environmental studies today. Frequently, corporations prioritize beneficial output maximization over model efficiency maximization, while they are equally concerned with minimizing nasty output minimization. At the same time, the manufacturing process is unavoidably enriched by a wide range of contaminants and wastes, including greenhouse gases and other forms of contamination. Maintaining a healthy balance between environmental performance and growth in the economy are linked is essential. Let n be the number of components of the energy vector, economic and environmental variable with entity. A common practice in developing the EVI to rank environmental performance of numerous entities, each underlying entity is ranked according to an environmental index, which can be differentiated from one another by the choice of ordering based on Rn. EVI can also be developed using the mapping function I = Rn→R, which may meet the following condition:

$$\mathbf{V}_k \succcurlyeq \mathrm{V}_l \Leftrightarrow \mathrm{I}(\mathrm{V}_k) \geq \mathrm{I}(\mathrm{V}_l) \forall k,\ l \in \{1, \ldots, K\} \tag{1}$$

Conversion functions are used to show how the basic units n-factored evaluation can be changed as:

$$\mathrm{F} : (\mathrm{V}_{k1}, \ldots, \mathrm{V}_{kn}) \rightarrow (\mathbf{f}_1(\mathrm{V}_{k1}), \ldots, \mathbf{f}_n(\mathrm{V}_{kn})) \tag{2}$$

When it comes to the extension, the acceptable transformation is involved in this manner as stated by Galvão et al. (2011) and Son et al. (2014) that satisfies, according to EVI, a series of numerous fundamental entities, each of which is expected to elect invariant, is used to evaluate the acceptable transformation of the underlying indicators in order to construct an EVI index for economic, energy, and environmental indicators in each of the three categories.

$$\mathbf{V}_k \succcurlyeq \mathrm{V}_l \Leftrightarrow \mathrm{F}(\mathrm{V}_k) \geq \mathrm{F}(\mathrm{V}_l) \forall k,\ l \in \{1, \ldots, K\} \tag{3}$$

Using a ratio scale and only positive variables, this study (Rasoulinezhad and Taghizadeh-Hesary, 2022) found that the geometric mean produced an important index, proving the geometric mean's significance. In order to quantify alternative aggregation procedures for the development of energy and environmental indices, Ye et al. (2022) developed criteria for estimating information loss. It was also described in detail how Liu et al. (2021) developed the non-compensatory aggregation method, including its use in energy and environmental studies. In addition to the normalization and aggregation of data, a variety of other studies are conducted using composite indicators and weighting.

The DMU0, on the other hand, is efficient if pollution-free environmental efficiency is the primary goal of the study. When it comes to creating an environmentally friendly DMU0, model number 4 is used, primarily for assessing economic efficiency using the SBM model, which utilizes DMUs' common input and output variables. DMU0 is only efficient when slacks are equal to zero, and only in this case does model 3 meet this requirement. It generates environmental efficiency values when model no 2 is used, while model no 3 generates economic efficiency values when an optimal adverse output from model no 2 is used as a fixative level. According to the findings of Chen et al. (2021), the combined index developed by the researchers can be used for both environmental and economic efficiency modeling. Even though these efficiency values were replicated, the process of obtaining this score has been lengthy. A non-parametric approach in conjunction with linear programming was used in this study to create an index of energy efficiency (EEE) by calculating the average sum of the binary efficiency values. With this, we can classify the most effective frontier practices and assess the relative performance of each of the underlying indicators in light of inputs and outputs from comparable and quantifiable sources (Nawaz et al., 2021).

To demonstrate the systematic productivity and performance of various objects or decision-making units, researchers have turned to data envelopment analysis (DEA), also known as DEA assessment (Bhuiyan et al., 2018; Zhang et al., 2022). It is used to evaluate energy and environmental performance by taking into account the difference between desirable and undesirable outcomes. Zhou et al. (2022), laid the groundwork for the acceptance of a non-parametric DEA frontier practice to measure the undesirable outputs of energy and environmental performance. To distinguish between certain output and input variables, the underlying vectors of variable are exchanged through another set of underlying variables X k,Y k = (xk1,· · · ,xkm,yk1,· · · ,yks) are both input and output vectors. This has the effect of reducing the amount of primary energy used. 20% of the energy consumption can be saved if the DMU's value equals 80% (Xiong and Sun, 2022). An assessment of energy and environmental techniques (Guo et al., 2022) is the sole focus of this article. For example, the efficiency of energy-related emissions is measured by Li et al. (2022). To improve environmental performance, Saeed Meo and Karim (2021) offer an SBM measure that uses poor output as an input. As long as you have input vectors that can be used to produce a certain level of output vectors. There is a plethora of possible input-output combinations when X∈ and outputs X∈ are used together.

$$
\begin{aligned}
S = \{(X, Y): S = &\sum_{k=1}^{K} x_{ik} z_k \le x_{i,} \quad i = 1,\ldots, m \\
S = &\sum_{k=1}^{K} y_{rk} z_k \le x_{r,} \quad r = 1,\ldots, S \\
S = &\sum_{k=1}^{K} z_k = 1, \quad i = 1,\ldots, m \\
&z_k > 0,\ k = 1,\ldots, K\}
\end{aligned} \tag{4}
$$

In contrast to Model 4, which only modifies CO_2 emissions, Model No. 5 modifies all negative outputs. This can be seen by comparing Model 4 to Model 3. Furthermore, the author emphasizes the importance of Model No. 4, which is the DEA model with an adverse output placement (Zhang et al., 2021b). The method considers the inability to effectively deal with the undesirable output when processing the desired and undesirable outputs in that order. On the contrary, it treats each and every one of its inputs as if they were all identical.

$$
\begin{aligned}
&\max \frac{1}{ms}\left(\sum_{k=1}^{K} \frac{S_i^-}{R_i^-} \sum_{k=1}^{K} \frac{S_r}{R_r}\right) \\
&S = \sum_{k=1}^{K} x_{ik} z_k S_i^- = x_{0i},\ i = 1, \ldots, m \\
&S = \sum_{k=1}^{K} y_{rk} z_k - S_r^- = y_{0r},\ r = 1, \ldots, S \\
&S = \sum_{k=1}^{K} z_k = 1,\ i = 1, \ldots, m \\
&z_k > 0,\ S_i^- > 0,\ S_r^- > 0
\end{aligned} \tag{5}
$$

Econometric Estimation

The estimations are made using a panel country fixed-effects model. Countries' fixed effects (i.e., unobservable factors) are shown in Eq. (1). All the time-invariant variations between countries are accounted for by the country fixed effects (such as cultural factors). To be clear, panel fixed-effect models are frequently employed in studies examining the causes of air pollution. The first model is written as:

$$
CO_{2it} = \beta_1 GF_{it} + \beta_2 EE_{it} + \beta_3 X_{it} + v_{it} + u_{it} \tag{6}
$$

where is CO_2 emissions of country *i* at year *t*; *GF* represents green finance index and includes the current as well as one lag of this index; is the energy efficiency of country *i* at year *t and X* is a vector of control variables; v_i is the country-fixed effects; *i* = 1, . . ., n denotes the country; and *u* is the error term.

All variables, with the exception of the energy efficiency index, renewable energy consumption, and urbanization rate, are transformed into logarithmic values for the purposes of estimation and forecasting. Detailed descriptive statistics (mean and standard deviation) for the variables are provided in **Table 1**.

RESULTS AND DISCUSSION

Energy Efficiency

Although the specific trend of German CO_2 emissions has become significantly higher than the common trend over the past

TABLE 1 | Descriptive statistics.

Variable	Mean	Std. Dev.	Min.	Max.
EE	0.52	0.698	0.446	1
GF	0.302	0.0746	0.159	0.621
PGDP	10.13	0.576	8.528	11.53
RE	94.98	40.65	3.8	242.3
URB	54.11	13.65	27	90
IND	38.74	8.484	11.84	53.04
TRADE	30.34	36.54	1.69	172.2
FDI	2.258	1.728	0.01	8.19
EDU	8.829	0.985	6.59	12.68
R&D	1.47	1.061	0.2	6.01

few decades, it follows the common trend. Finally, average trends are increasing and emissions in Italy are trending horizontally. For instance, most developed countries seem to converge at the highest peaks, except for Canada and France, which seem to have a different path to efficiency, even though they started to be the most energy-consuming countries during this period. Fossil energy processes, which produce large amounts of carbon dioxide emissions, were largely responsible for the majority of global economic growth in the twentieth century. According to policymakers, any reduction in carbon dioxide emissions will have an adverse effect on the economy. The economies of major countries continue to struggle even with reduced emissions. like the United States can grow their GDP and their economic output, but pollution does not have to rise at the same time. This is based on new subjective evidence, however. That's because industries and economies are moving away from large energy-intensive technologies and toward smaller ones. Between 0.65 and 0.70 is a structural shift, efficiency, and the typical intensity of energy index Structural reallocation has resulted in an increase in energy intensity and a decrease in their energy efficiency. **Table 1** contains the individual indicator score of G7 economies. Shocking eco-friendly concerns, like a global warming, are connected with the use of abundant energy utilization because of prompt growth and development (Yao and Tang, 2021). This study employs the DEA models to assess the efficiency of energy consumption, environment-economy and CO_2 emissions for the G7 economies, the efficiency of energy use and CO_2 emission efficiency, separately, and economic efficiency and environmental efficiency. These pursue an equilibrium between the economic development and environmental performance of a country However, the comparative rankings indicate that France and Italy are the best amongst all considered members.

Energy concentration cannot be used to assess the efficiency of any country's energy consumption, as can be seen from a comparison of the two concepts' relative effectiveness in terms of energy consumption and concentration. Consequently, France and Italy were recognized as equally competent and well-performing countries during the periods, whereas Japan, Canada, and the United States are the last three economies among all G7 members for almost every year with respect to CO_2 emission efficiency. For all G7 countries, the efficiency scores are less than 0.50 for emission efficiency of CO_2, enlightening greatly significant variances among G7 economies in emission efficiency of CO_2. Additionally, the majority of G7 countries' research studies have greater points in environmental economic efficiency as compared to CO_2 emission efficiency, where Canada and France are the only two exclusions. Japan and France are the two milestones and bench-marking markets that were recognized as efficient in both CO_2 emissions and energy consumption. Considering a greater extent of economic and environmental efficiency, it is concluded that the majority of the G7 countries demonstrated better economic efficiency as compared to environmental efficiency. When studying the relationships between energy consumption efficiency and emission efficiency of CO_2, the study concluded that energy consumption efficiency and emission efficiency of CO_2 can help to decrease environmental condition.

This was achieved by assessing the environmental and energy equity. The energy intensity and environmental index analysis shows the best score, where the United Kingdom and the United States are the two countries with the worst results. For countries, maintaining economic development without affecting energy utilization is quite challenging -the development of energy-related efficiency in the world's major economies, while reducing energy waste and pollution Taghizadeh-Hesary et al. (2021) concluded that energy consumption and economic growth are directly related to energy and environmental efficiency.

Table 2 shows energy intensity and energy efficiency scores. In this study, energy, economy, and environmental indicators are used to measure energy, economic, and environmental efficiency and CO_2 emissions. The G7 countries' economic and environmental efficiency scores show the best undesirable output should be fixed to generate an economic efficiency score for environmental efficiency. In general countries with greater economic and environmental efficiency, according to the findings scores have a more efficient economy and environment than countries with lower economic or environmental efficiency scores. There are two countries in the world that are less efficient than France and Canada.

Econometric Estimation

The fixed effects are shown in **Table 3**. It appears that green finance development can increase the level of green productivity at the 5% level, based on GF coefficients as the primary explanatory variable. There is strong evidence it is possible to achieve a win-win situation with green investment and credit for both the environment and the economy, which in turn can lead to increased green economic development. As a result, in order to alleviate China's financial constraints, the country's central government should focus on this issue alone by businesses while undertaking environmental-friendly activities, which necessitates the development of an operating green financial system. Companies are more likely to do so to get actively involved in green economic development activities if they did this.

Evidence shows that most control variables are statistically significant in terms of their influence. The positive correlation between GDP per capita and R&D shows that the more economic progress and technological advancement there is, the greater the

TABLE 2 | Energy efficiency of G7 countries.

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Canada	0.51	0.45	0.49	0.41	0.55	0.59	0.55	0.68	0.49	0.63
France	0.88	0.87	0.94	0.88	0.97	0.93	0.88	1	1	1
Germany	0.47	0.45	0.41	0.51	0.37	0.44	0.26	0.34	0.33	0.38
Italy	0.88	0.82	0.86	0.77	0.69	0.77	0.72	0.66	0.74	0.76
Japan	0.52	0.54	0.61	0.45	0.26	0.26	0.21	0.24	0.19	0.22
United Kingdom	1	1	1	0.99	1	1	0.98	1	0.95	0.98
United States	0.46	0.45	0.41	0.46	0.34	0.35	0.37	0.39	0.37	0.39

TABLE 3 | Results of fixed-effects regressions.

Variable	OLS	Fixed effect
GF	−0.002	−0.001
	(−0.31)	(−0.029)
EE	−0.019***	−0.133***
	(−7.52)	(−9.31)
RE	0.026**	0.031*
	−1.992	−1.842
GDPpc	−0.007**	−0.111*
	(−2.018)	(−1.327)
Trade	−0.003***	−0.054
	(−4.052)	(−1.342)
Education	0.021***	0.0132
	−3.933	−0.895
R&D	0.012	0.236
	(−0.342)	(−1.358)
Urbanization	−0.007**	−0.009*
	(−2.269)	(−1.843)
Constant	1.022***	1.321***
	−18.55	−19.31
Observations	1,044	698
Firms	98	72
Likelihood	677.22	423.62
Wald chi (2)	543.82	488.42

*Significance levels: * = 0.1, ** = 0.05, *** = 0.01.*

potential for increasing green productivity. The findings of Sun et al. (2022) are supported by these findings. However, R&D return the local scientific and technological capabilities that have a positive effect on economic growth Zhang and Vigne (2021). Research and development, on the other hand, can improve the quality of the environment (Huang et al., 2021). The coefficients of trade indicate that the amount of green output decreases with time the structure of how much and how much energy is used in industrialization. We had expected these results, and they confirm our suspicions about China's excessive urbanization and reliance on coal consumption (Chien et al., 2021; Lee and Lee, 2022; Ning et al., 2022). According to the EDU coefficient, a high degree of traditional education is associated with low green productivity. The wealth effect in emerging economies is to blame for this. To put it another way, a higher level of education tends to lead to an increased demand for energy, which has a negative impact on the environment (Sun et al., 2022).

In addition, 27 percent of coal was used, and there was a noticeable change in 2009 As a result, in 2009, OECD countries reduced their use by around 4.7%, which is on par with the rate in 2000. Sustainable development requires that energy demand be met without compromising the need for environmental protection (Usman et al., 2022). In most cases, the political economy provides a financial foundation for evaluating the degree of energy efficiency in relation to power output per unit. A developing various study are settled in Germany, which have added to activity efficiency of energy by specializing in the analysis of efficiency of total-factor. Whereas, our findings are supported by the study of Hassan et al. (2022). According to these studies, a combination of energy inputs and resources such as greenhouse emissions are used during the combined production process. Zhao S. et al. (2022) evaluated electricity based on a rank-based system. Analysis of energy efficiency in the G7 countries was conducted by Zhang et al. (2022) using Data Envelopment Analysis (DEA) to evaluate the total-factor structure. Economical models require the factors that lead to higher energy performance measures to be taken into account. When Zhao X. et al. (2022) conducted their research to provide environmental upgrading submissions, they relied solely on the investigation of energy potency and the environmental Kuznets curve.

The empirical evidence of this lies beyond the scope of the present study. Therefore, the proposed research study comprises GHG releases, i.e., emissions only for the purpose to unearth the real image of eco-friendly degradation. Renewable energy reduces the environmental deterioration and climate vulnerability (Zahoor et al., 2022). Furthermore, Canada has its energy security and has massive reserves of crude oil, and has vital and effective policies.

Sensitivity Analysis With Another Measure for Green Finance

The results of sensitivity analysis are shown in **Table 4**. Equation 1 is re-estimated by replacing the green finance index substituting other proxies for green financing. The total each country's Climate Bond issue from 2010 to 2019 is known as Climate Bonds. The Climate Bonds Initiative database serves as the source of this variable's data. An important relationship between GDP growth and greenhouse gas emissions has been found (it caused increase of GHG releases, i.e., emissions with the perspective of Canada due to growth in GDP). GHG emissions, i.e., emissions were positively impacted by the gross domestic product growth that matches, i.e., GDP. When it comes to per capita emissions of greenhouse gases and energy security, countries that use more energy face similar issues as other countries that use more energy (Hao L. N. et al., 2021; Tawiah et al., 2021). Fossil fuel subsidies have been linked to higher GHG emissions and decreased energy security in both developed and less developed countries, according to numerous studies. Furthermore, a number of in both developed and welfare

TABLE 4 | Sensitivity analysis.

Independent variables	(1)	(2)	(3)	(4)
Climate bonds	−0.2702***	−0.1319*	−0.1284*	−0.1933***
	(0.0558)	(0.0769)	(0.0737)	(0.0600)
GDP	1.3807***	0.9317***	0.8345***	1.2642***
	(0.1133)	(0.1896)	(0.2447)	(0.1110)
Population		0.3668***	0.4566**	
		(0.1231)	(0.1810)	
Urbanization				0.6599
				(0.3956)
RE			−1.5191	−0.5514
			(2.112)	(1.0316)
R^2	0.7356	0.7720	58.77	45.12
F-statistic	83.62***	79.19	0.7780	0.7767
Observations	61	61	61	61

*Significance levels: * = 0.1, ** = 0.05, *** = 0.01.*

countries, fossil fuel consumption is increasing than their less developed counterparts (Ngo, 2022). Similar strategies are being discouraged because of the growing trend toward renewable energy. In Australia, a reduction in subsidies is expected to reduce GHG emissions by 12 percent by 2030 (Feng and Wu, 2022). According to GHG data, most of the energy consumed in those countries originates in the form of fossil fuel. GHG emissions are lower in countries that use more renewable energy, such as Iceland, which has 77.03 percent renewable energy and "720" GHG emissions. Emissions per kilowatt hour of energy used (Feng and Wu, 2022).

Discussion

In order to the environment and a clear production process must be maintained at all times process and the use of renewable energy are necessary (Dong et al., 2022). Carbon dioxide levels in the atmosphere are expected to rise as a result of an increase in the amount of energy used by industries, according to the study by Dong et al. (2022). This year, CO_2 concentrations in the atmosphere reached 400 ppm on an annual basis, which is 40% higher than the level in 2016. Emissions of carbon dioxide (CO_2) have decreased by nearly half since 1980, according to Debrah et al. (2022) and Khan H. et al. (2022).

The United Nations (UN) eco-friendly program is reflected in the energy policies of European countries. A wide range of options are available thanks to new warning technologies and intelligent monitoring. Different and specific methods are recommended to ensure sustainable, environmentally friendly, and crystal-clear production. It is only possible to maintain a clean production through continuous application of a mutually cautious recyclable strategy, which maintains because of its environmental friendliness. Due to the fact that immaculate creation's application in a wide range of industries, as it necessitates the consumption of the atmosphere's natural resources (Hu et al., 2022). For example, Proper waste management would be ensured by an efficient environmental management system through investment in research and development. It's impossible to know how technological advancements will affect carbon emissions without evidence. Because of a rise in economic growth and greater openness to trade, research and development may have an impact on environmental quality, given the positive impact on the expansion and trade of R&D. Energy and environmental efficiency may be enhanced by new technologies, but increased production may still necessitate greater use of natural resources, resulting in higher emissions of CO_2. As existing knowledge reserves grow, it becomes more difficult to achieve new developments, resulting in lower levels of R&D over time. Economic expansion, on the other hand, necessitates a greater use of natural resources.

Historically, the G7 countries have been larger energy consumers. Various studies on these countries assess their economic growth, energy efficiency, and resilience by considering poor output, energy input, and non-discrimination. However, the contribution of developed countries toward global energy consumption has declined over time. Generally, over the past three decades, the G7 countries have been considered and characterized like the countries with a large industrial volume of production, international gas releases, i.e., emissions, energy utilization, and trade. The goal of this study is to determine how much energy is being used intensity, energy efficiency, and environmental index of these nations, as they contribute entirely a huge volume of releases, i.e., emissions and that is equal to the total worlds' emissions. Thus, energy consumption is a major concern because of an increase in foreign-imported energy prices. In the meantime, the extensive use of imported oil increases the CO_2 emission level, which ultimately causes global warming and climate change, decreases farming yield, and threatens human life. In this situation, a new philosophy is a necessity for energy consumption and sustainable economic growth. The logical reason behind selecting the G7 countries is that it shows the divergent results and contains the alarming figure of energy consumption and CO_2 emission (Hao et al., 2022; Khan I. et al., 2022). Trends in the United States, Canada, and France are usually much higher than the average trends, although CO_2 emissions in France have converged into a common trend over the past three decades. Japan and the United Kingdom are clearly below the average trend, although UK carbon dioxide emissions have been closer to the average trend in recent decades.

CONCLUSION AND POLICY IMPLICATION

Eco-friendly index estimation and alternative methods when it comes to evaluating the effectiveness of energy use and environmental impact are the consequences of the proposed research. With less GHG emissions and renewable energy releases metrics, the lack of efficient environmental performance suggests an overview of GHG's releases (toxic emissions). Measuring energy concentration and energy efficiency was a perplexing issue that is being faced around the globe to resolve this, an environmental, i.e., eco-friendly index was developed. Keeping in view to construct an eco-friendly index of all G7 nations, applied both arithmetic mean aggregation and DEA, i.e., Data Envelopment Analysis to develop a mathematical aggregation tool. To support the methodology of this study, the standardized EVI was developed by adopting a non-parametric frontier approach. Therefore, in future, further assessment on decision-makers' preferred weight and rank information may be incorporated. Results of the proposed research work suggest implementing the below recommendations. The main factor of global warming is the utilization of energy; therefore, it must be reduced. Research and development expenditures increase by 1% for every 1% increase costs, Canada, France, Germany, Italy, Japan, and the United States reduce carbon dioxide emissions by 0.18, 0.27, 0.22, 0.09, 0.31, and 0.32%, respectively. In the United Kingdom, a 1% An increase in R&D spending will result in a 0.62 percent increase in emissions, but after accounting for this discrepancy, the effect will be negative. The turning point for valid environmental situations in all countries, except Japan was between $6933 and $36,255.

We Proposed the Following Policy Framework

- In the short term, these countries may continue to operate at a relatively high level of inefficiency unless their governments change their management style or alter their policies. 1. To put it another way, short-term policies in these economies will increase energy security and carbon emissions. Even though developing countries are making steady progress, developed economies are reluctant to follow suit until their own performance improves.
- It has also been found that by focusing on the economies of each country in the proposed G7 group and comparing their environmental performance, convergence appears to be greater or stronger than it would have been otherwise.
- It is imperative that developing countries take steps to encourage the growth of renewable energy use. Reducing the use of fossil fuels, for example, is an important step toward reducing energy-related carbon dioxide emissions and fostering a green economy. In addition, the growth of fossil fuels should be regulated to ensure sufficient growth. Developing low-carbon energy requires space. The most appropriate and cost-effective way to reduce the environmental impact of energy production is to improve energy efficiency.
- As a result of extreme weather conditions, disasters, and natural disasters, policymakers must increase their ability to resist energy shortages; this would improve energy equity. Oil import risks could be reduced and outdoor oil dependence reduced if energy prices are fixed and not affected by supply and demand or by the use of renewable energy sources.
- Thus, G7 countries should continue to implement innovation-driven approaches and move toward a more enhanced ability to innovate; this can help improve performance by commercializing research and development from G7 nations. Consequently,
- G7 countries play a supporting role for the region's ecological environment, but the province is the most polluted G7 region. In order to protect their natural environments, countries in South Asia must enforce strict environmental protection legislation and implement shared avoidance, control, and law measures. This would improve environmental quality to the point where it would be more robust to support and guarantee superior economic growth.
- With regard to those who live in cities ranging from small to large have the potential to improve environmental efficiency, although it is expected that industrial transfer demonstration zones will positively contribute.
- In order to reap the benefits of policy-making connected to the industrial transfer demonstration zone, the zone's policy welfare should be continually improved.

DATA AVAILABILITY STATEMENT

Data will be provided on reasonable request from corresponding author.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

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Does Green Financing Develop a Cleaner Environment for Environmental Sustainability: Empirical Insights From Association of Southeast Asian Nations Economies

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One of the most frequently used terms in climate change discussions is environmental sustainability. With economic growth and foreign direct investment as moderator factors, this study investigates the influence of green finance and financial development on environmental sustainability and growth in ASEAN economies from 2012 to 2019. ADF and Phillip-Peron (PP) unit root tests, fully modified least square (FMOLS), were employed for long-run empirical estimates. A substantial body of evidence supports the study's findings using VECM technology. Green financing was negatively associated with CO2 emissions. However, environmental sustainability in ASEAN is favorably associated with green financing. It is also worth noting that green financing promotes environmental sustainability at the expenditure of economic growth. Financial development, foreign direct investment, R&D investment, and green technology foster economic expansion at the price of environmental sustainability. There are still many fences to green finance that need to be addressed, including pricing CO2 emissions and reforming inefficient nonrenewable fossil fuel subsidies. Local governments play a vital role in eliminating these barriers and addressing disincentives. It is recommended that policymakers push the financial sector to adopt a green finance strategy to further the goals of long-term sustainable development. Industry must integrate multiple objectives, such as inclusive growth and environmental protection and productivity, through an even broader range of legislative frameworks ideal for decoupling growth from social and ecological unsustainability, at the heart of the green manufacturing process.

Keywords: cleaner environment, green financing, climate change, environmental sustainability, ASEAN economies

INTRODUCTION

Indonesia, Malaysia, Singapore, and Thailand molded the Association of Southeast Asian Nations (ASEAN) in July 1967 to endorse economic development, social improvement, and cultural development. It began in 1984 with Brunei, followed by Vietnam in 1995, Laos and Myanmar in 1997, and other countries. One million square miles and more than 600 million people populate the ASEAN region (4.5 million km^2). For example, ASEAN's most important initiatives include joint research and technology cooperation programs among member countries under cooperative peace and shared prosperity (Huang X. et al., 2022). This regional organization's most significant efforts are centered on the expansion of commerce between ASEAN countries and other countries and programs for joint scientific research and technology cooperation among the member governments. Some have challenged growing regional integration as threatening international institutions and isolating governments outside the region (Feng H. et al., 2022; Rao et al., 2022; Xiang et al., 2022a). They fear this will happen. After the Asian financial crisis of 1997–1998, it is suggested that liquidity come from outside the area. As a result of this, the Chiang Mai Agreement has spurred the development of a truly multilateral organization for bilateral swap agreements and the creation of an Asian currency.

For centuries, the financial industry has served as a tremendous force for human advancement (Nureen et al., 2022; Xie et al., 2022). Savings from all across the world must be used wisely, and here is where the global financial system comes in handy (Irfan et al., 2020a). People's quality of life can be improved with the proper use of investment (Iqbal et al., 2020; Irfan et al., 2020b; Iqbal W. et al., 2021; Xiang et al., 2022b). Many people have put their funds in environmentally hazardous ventures and real-estate bubbles as a result of the collapse of the banking system (Rehman et al., 2020). As a result of the financial sector's previous disregard for the ecosystem, environmental problems such as territory loss and resource lessening (Ahmad M. et al., 2021; Fang et al., 2022; Irfan et al., 2022a), environment change (Dagar et al., 2022; Islam et al., 2022), and effluence have emerged or worsened (Irfan et al., 2022b).

Although the importance of finance in the anthropogenic (i.e., human influence on the ecosystem), slight has been done to merge environmental problems into finance (Tawiah et al., 2021). In recent years, investments in sustainable growth have received more attention from the financial sector (Wu et al., 2021). Green financial products, according to Habiba and Xinbang (2022), can aid in the creation of a greener world. The terms green finance and sustainable finance are interchangeable, as are climate finance. Investments that improve the environment are referred to as green finance (Yang et al., 2021; Chishti and Sinha, 2022). On the other hand, climate finance is financing that attempts to sustenance climate change mitigation and adaptation efforts (Abbas et al., 2020; Chien F. S. et al., 2021; Yu et al., 2022). Financing tools for sustainable development are what bind all of these terms together. Investing in renewable and clean energy projects is essential for reducing carbon emissions and their harmful effects on human health and the environment (Irfan and Ahmad, 2021, 2022). It incorporates environmental considerations into financial decision-making. These environmental and sustainability considerations will be enhanced through the use of green finance to fund climate-neutral as well as resource-efficient technologies (Bhardwaj et al., 2022).

In recent years, green finance has also gained much attention as an emergent paradigm of finance development (Mikhno et al., 2021; Chen et al., 2022). Green finance and finance have become problematic terms in this context. According to Abbasi et al. (2022), green finance is a new financial pattern that combines environmental conservation with economic profit. Eco-friendly finance is an essential component of the transition to sustainability, and its development aims to reinforce particular financial features to enhance environmental quality (Wei et al., 2022). As of this writing, academics have centered on the fundamentals of green finance, such as how to integrate environmental protection into finance (Tang et al., 2022) and how to build green finance operating mechanisms within environmental protection systems (Sun et al., 2021), and the role of government in green finance implementation (Franco et al., 2021). Empirical investigations on the connection between green finance and the environment also play a role in this topic. A recent study by Weihong et al. (2021) indicated that lessening carbon emissions by using green financing policies had a favorable impact. However, the effects were short-lived and lacked continuity. Green economic growth is facilitated by the public from green finance, as Chien F. et al. (2021) have demonstrated. When applying the spatial econometric model, Nasir et al. (2022) discovered green finance's environmental spillover effects. Green bonds, green loans, greenhouse mortgages for commercial buildings, ecological home equity programs, go green auto loans, Small and medium-size enterprises expedited loans, and climate credit cards have been developed by financial intermediaries and markets. Australians also started a long-term financial mechanism called the Environmental Deposit Initiative, which aims to assist climate change and sustainable development by providing medium- to long-term funding for environmentally friendly company ventures.

Few studies look at regional heterogeneity and factors that drive green finance and environmental sustainability to evolve in concert. This is obvious from examining the previous studies on green finance and environmental sustainability. According to a literature assessment, green finance has thus far been measured using a pretty straightforward method. Most academics use one or two indicators, which lack a broad perspective. The originality of this study is based on the fact that: As part of the global fight for efficient resource allocation and sustainable development, this article attempts to highlight the importance of developing a green financial system. As a result, economic growth can protect and improve the environment (Saha et al., 2022). There are still considerable hurdles to overcome in developing a green financial market, even though it improves resource allocation efficiency and accelerates the transition to a more sustainable growth model.

Green financial solutions aren't all the same, and there aren't as many options as there used to be. Green businesses are hindered because a single product can be defined in various ways (Zhang et al., 2021). ASEAN's growth has been primarily driven by the green credit and green bond markets. Although new green financial products can draw public money third-party authorization bodies lack a clear definition of the standards for evaluating green initiatives, simply leading to the phenomenon that green projects are expelled by non-low-carbon projects (Mngumi et al., 2022).

While there are positive externalities and good environmental advantages to green projects, An et al. (2021), When compared to more traditional projects, green ones suffer from a lack of necessary skills and a high initial cost (Feng S. et al., 2022). Enterprises' passion for green creation will decline if there is less assistance from the green project intermediary, information services, and other specialized organizations. There is a demand for innovative financial and ecological economics expertise in developing green financing. A scarcity of qualified individuals hampers sustainable growth in green finance.

The aim of the study is to investigate the impact of green finance on environmental sustainability. Heterogeneous interests characterize green financial engagement (Wang et al., 2021). Policy and regulations developed by the ASEAN promote green finance. As a result, ASEAN incentives and involvements do not substantially address the issue of the green driving force in firms (Ning et al., 2021). So it will be tough to execute the policy system (Mastini et al., 2021). The only option is to go for the highest possible profit margin for businesses. A dynamic green financial market relies heavily on financial institutions. Market activity is minimal, and revenues aren't very large because innovative financial products are easy to understand (Li et al., 2022). Encouraging the flow of social capital into green financial markets is a difficult task. Consumers purchase green items according to utility maximization (Huang H. et al., 2022). Green financial markets can't grow if consumers aren't encouraged to participate in environmental conservation through the correct use of subsidies.

The rest of the article is organized as follows: Section "Literature Review" offers a brief overview of relevant literature and outlines the research's primary findings. Introducing the green finance operating mechanism, defining parameter notations, making corresponding assumptions and building a basic evolutionary of the interactions between a clean environment, foreign direct investment (FDI), financial institutions and environmental sustainability are all covered in Section "Methodology." Varied incentives have different effects on VECM and FMOLS outcomes in Section "Results and Discussion." Simulates and analyses the long-term viability and strategy of green financing and its impact on participating entities. Section "Conclusion and Policy Implications" concludes the discussion.

LITERATURE REVIEW

The Connotation of Green Finance

Research on green finance in international academics often goes through four stages: the emergence of green finance, sturdy development, surging growth and speedy growth. From 1998 to 2002, the notion of green finance was developed. According to Ning et al. (2022), Green finance is a vital link between the financial and environmental industries and critical financial innovation in the quest for environmental conservation. The green finance theory underwent a steady evolution between 2000 and 2005. For (Jinru et al., 2021), environmental protection was the starting point for developing the theoretical foundations of finance, which included the financial services industry as a distinct service sector. Green finance theory went through a rough patch between 2006 and 2011. Financial organizations are developing green financial services in underdeveloped nations and emerging international nations. Anh Tu et al. (2021) performed surveys and in-depth explorations and assessments on regional environmental investment. The notion of green finance was rapidly evolving in 2012. Rights price marketplaces, individual investors' knowledge, and financial institutions' sustainability in the development of the green company were all explored. These findings demonstrate that foreign researchers' knowledge of green finance has evolved from phenomenon to essence, from simple to complex. This growth has occurred in tandem with the growing worldwide awareness of environmental challenges. Ecological sustainability is the goal of a green economy, defined by Jinru et al. (2021) as the coordinated development of those above three.

Compared to academic circles in other nations, domestic research into green finance theory began later in the United States. There are primarily three representative viewpoints on what it means to do green finance: According to Zhang et al. (2021), green finance is a special financial policy that prioritizes the provision of financial services to environmentally friendly and clean businesses. According to Nawaz et al. (2021), green finance needs the financial industry to safeguard the environment. Sun et al. (2022) defined green finance as a financial instrument novelty designed for environmental protection. On the other hand, the third viewpoint is more comprehensive and has gained widespread acceptance in the academic world here in the United States. There are numerous studies out there looking at green finance from this standpoint. Zhang and Vigne (2021) studied green finance's meaning, dimension, and structure. With the help of data from six central Chinese provinces, Zhang and Vigne (2021) employed a fixed-effect model to examine the impact of green funding on provincial economic development and proposed appropriate remedies.

The Environmentalization of the Association of Southeast Asian Nations Economy

Humans have a strong desire to sustain stability between the economy and the environment, leading to the environmentalization of the economy. It is a decision-making science investigating economic progress and inter-regional links from a macro level. Kenneth Boulding, an American economist, was the first to propose it in 1966. He argues that environmental economics is a subject that analyses the interaction between environmental systems and economic structures and encompasses modern-day environmental economics and regulations touched by green financing. The economic growth model will lead to resource reduction, ecological deterioration, and finally, economic collapse if it is based solely on growth. As Sun et al. (2022) showed, the study region's renewable energy sector's financial development has been a substantial positive element of the renewable energy sector in the study area. Using the objective rules of ecosystems and ecological processes, Jin et al. (2021) contend that humans must control and regularize the natural environments in which they live. Ning et al. (2022) said that the mechanical study technique shows that the economic-centric development model will ultimately lead to the nations' economic crisis if the ecological rules are violated, and the ecosystem is damaged. The ecological economy can only be realized if methodology and ecology are incorporated into economics and harmoniously develop the environment. According to Sinha et al. (2021), ecological economics focuses on environmental and economic challenges that aim to prevent environmental destruction as a result of economic growth. Environmental, economic indicators, environmental development, and environmental energy research are the keys to success. Other methods, such as studying ecological models, are used to understand better how the economy and the environment are intertwined. This helps solve economic ecology issues and uncover the economic ecosystem's internal significance and requirements. The idea of economic environmentalization is to grow the economy while also protecting the environment on which humans depend, according to Zheng et al. (2021). In order to attain this, environmental protection must be prioritized in all dimensions of environmental protection and economic development actions must be improved. Such improvements include enhancing the production process through advanced technologies, converting harmful toxins liquidated during the production procedure, and utilizing clean energy. To summarize, economics and the environment are mutually supportive of one another. Developing the economy in accordance with the principles of ecology is known as environmental economics. The only way to create a civilization based on ecological principles is to apply environmental economics.

Green Finance and Environmental Sustainability

Only a small number of research have thus far examined the link between finance and ecology. Environmental sustainability can be attained by arranging funds for solar energy, according to Zhou et al. (2020). Environmental finance/sustainable financing was found to be the most effective method of reducing environmental degradation in a study by Chishti and Sinha (2022). Investing in renewable energy is one way that sustainable finance/green finance promotes new technology and innovation (Ansari et al., 2022). Green bonds (a proxy for green finance) and CO2 emissions have been overlooked in prior studies. Environmentally friendly or pollution-reducing initiatives are the only projects that can be financed with proceeds from green bonds, which are long-term financial securities. Some examples include clean water, solar energy and clean transportation initiatives funded by green bonds.

Green bonds are the best option for green financing technology since they offer long-term capital funding at a low cost. Fossil fuels dominate energy investments. As a result, it is critical to move financial resources away from nonrenewable energy sources and toward sources that reduce carbon emissions (Alola et al., 2022). Investments in green bonds offer a wide range of benefits in addition to their environmental benefits. Introducing green bonds to finance renewable energy projects is particularly attractive. Low-risk, steady-return investments include those in fixed-income securities. Bonds with these characteristics will appeal to domestic and institutional investors, making green financing more attractive. An investor's risk appetite can be accommodated *via* the issue of bonds, which widens the credit pool (Camana et al., 2021). Direct investing in green technology and clean energy is made possible by spreading liability over a wide range of investors through bonds. Finally, the presence of a secondary market offers investors liquidity and a way out. Those with temporary investment prospects are likewise drawn to this trait. Green bonds are a smart way to increase investments in green technology and renewable energy because of these facts (Camana et al., 2021).

Despite the popularity of green bonds, another option for funding green technology and clean energy projects is equity financing. Investors are unwilling to capitalize on sin stocks that hurt human health and the environment or exploit societal comfort, regardless of the rewards they provide. According to recent years of equities market data, investments in environmental and socially responsible stocks (ESR) have been rising over the last few decades, focusing on the companies' policies on social, environmental and corporate governance issues, such as human rights. Despite the COVID-19 epidemic, sustainable investments worldwide totaled USD 35.3 trillion, indicating a 15% gain in two years. ESG equities have also been more hardy to market slumps like the global financial crunch, commodities price fluctuations (Saint et al., 2021), or the COVID-19 pandemics (Zheng et al., 2021). Using equity markets to finance green technology and clean energy projects has a number of advantages. It is safe for investors to participate in this market because of the stringent disclosure rules. Dispersion of ownership across shareholders implies that different points of view from various shareholders might be considered while evaluating projects.

METHODOLOGY

Variable Selection

This study builds a green finance index system that covers five elements, including green securities, green credit, green investment, green insurance, and carbon finance, in order to quantify ASEAN's green finance more objectively and thoroughly. To advance green innovation and green development, R&D investment is essential. This has been proven

TABLE 1 | Variable definition.

Variables	Signs	Definition
Green finance	GF	Green finance index system
R&D investment	RDI	R&D internal expenditure/GDP
Green technology	GRT	Clean Technology Index as a proxy for green technology
Human development index	HDI	Urban population/ total population
CO2 emission	CO2	CO2 emissions per capita
Foreign direct investment	FDI	Actual Foreign direct investment/GDP
Economic growth	GDP	Total gross domestic product

TABLE 2 | Descriptive statistical results of variables.

Variable	Mean	Std. Dev	Min	Max
GF	0.297	0.149	0.105	0.826
RDI	1.663	1.138	0.241	6.111
GRT	47.90	8.785	19.56	62.002
HCI	58.19	13.82	30.56	94.08
CO2	30.205	42.23	1.218	538.12
FDI	3.194	5.004	0.0042	32.20
GDP	16.643	10.13	3.17	60.27

to have a threshold effect. Consequently, the threshold variable in this article is the ratio of R&D internal spending to GDP, which represents R&D investment (RDI). Other variables are given in **Table 1**.

Data

Association of Southeast Asian Nations countries are included in the study's data set, spanning from 2012 to 2019. We used metric tons of CO2 emissions per person, kilograms of oil equivalent per person, and % of total energy derived from combustible, renewable, and waste sources as our clean energy variables. We also looked at the total amount of exports and imports and the money supply to GDP as our indicator for financial development. We used data from World Bank databases for this analysis (WDI).

In terms of data sources, the WDI and the wind databases are used to generate green credit and green security data, respectively. Global Energy Statistical Yearbook provides data on carbon financing and energy input, while Insurance Yearbook provides data on green insurance. The Global Science and Technology Yearbook provides data on R&D spending. Additional information comes from the Global Statistical Yearbook and Global Environmental Statistical Yearbook. For this article's purposes, we use 2012 as the base year for all price indicators, and we adjust total import and export volumes and real FDI to reflect the current exchange rate in CNY.

Descriptive Statistics of Variables

The descriptive statistics and pairwise correlations between the various variables are included in **Table 2** of the article. It shows that CO2 emissions range from around 1.218 to around 538.12 metric tons, per capita GDP ranges from around 3.17 to around 60.27, and green technology ranges from around 19.56 to around 62.002. Renewable energy consumption ranges from 4.8% to around 3.9% over the sample period.

Nonrenewable energy consumption has the strongest link with per capita CO2 emissions, whereas financial development has the lowest correlation. However, the foreign direct investment (FDI) is positively connected with CO2 emissions, indicating that increasing renewables can help ASEAN countries reduce their use of nonrenewable energy and hence reduce their CO2 emissions. The analyzed correlation matrix coefficients show that the multicollinearity problem has no significant impact on any estimates.

Table 3 provides descriptive statistics for individual countries. Among ASEAN members, the country of Brunei Darussalam emits the most CO2 per capita, with a 40.322% increase since 2012. Singapore and Malaysia produce significant CO2 emissions in 2020, with per capita emissions at 8.941 and 7.982 metric tons. On the other hand, Singapore saw a 25.317% decrease in CO2 emissions during the same period. Malaysia's CO2 emissions have risen by 39.545% since 1990. In Thailand, Vietnam, and Indonesia, CO2 emissions have also increased. Cambodia and Vietnam saw the greatest increases in CO2 emissions between 2012 and 2019. The country's CO2 emissions are still below the average for all ASEAN economies, despite the country's economic growth.

Brunei Darussalam is ASEAN's most energy-efficient country. There has been a 30.308% increase in Brunei Darussalam's kg of oil equivalent per capita consumption since 2012. Energy consumption in Singapore is currently the second-highest in the ASEAN region. Energy consumption in Singapore has decreased between 2012 and 2019, indicating that renewable and cleaner energy sources are better for the economy and the environment. The economies of Malaysia and Thailand are both using a lot of energy to grow. Compared to 2012, Malaysia's energy consumption has increased by 37.092%. Between 2012 and 2019, Thailand's energy consumption increased by more than 67%. Among the ASEAN nations, Cambodia uses the least energy. The Philippines' use of energy decreased by 3.732%.

Cambodia and Vietnam have made the most progress among the ASEAN countries regarding green finance. In 2012, only 5.987% of Cambodia's GDP was attributed to financial development; by 2019, that number had risen to 99.986%, a gain of 1570.051%. A remarkable increase of more than 240% was seen in the share of financial development in Vietnam's GDP from 2012 to 2019, rising from 39.290% to 133.923%. Malaysia's financial development has increased by 5.405% since 2001, which is not encouraging for the country's prospects for economic growth. Financial development has slowed in Brunei Darussalam by more than 27%, indicating that a weak financial sector has hindered the country's economic growth and development. Though financial development in Indonesia was improved from 2012 to 2019, the country still holds one of ASEAN's lowest positions.

According to country-specific data, the ASEAN region's FDI statistics are mixed at best. FDI fell in all ASEAN economies except for Cambodia, Vietnam, and Brunei Darussalam from 2012 to 2019. There was a 52.445% drop in Indonesia's FDI index,

TABLE 3 | Description of statistics (Country-specific).

Country	Variables	2012	2019	% Change
Brunei Darussalam	GF	13.253	18.597	40.32%
	GDP	6492.724	8460.589	30.31%
	RDI	53.633	38.784	−27.686%
	CO2	108.718	110.197	1.36%
	FDI	36171.81	30717.95	−15.077%
Cambodia	GF	0.181	0.566	212.71%
	GDP	276.504	406.173	46.90%
	RDI	5.987	99.986	1570.05%
	CO2	113.743	126.342	11.08%
	FDI	453.969	1374.579	202.79%
Indonesia	GF	1.375	1.956	42.25%
	GDP	742.97	872.424	17.42%
	RDI	18.155	33.154	82.62%
	CO2	69.793	33.19	−52.445%
	FDI	2191.574	3756.907	71.43%
Malaysia	GF	5.72	7.982	39.55%
	GDP	2145.964	2941.948	37.09%
	RDI	127.232	134.11	5.41%
	CO2	203.364	116.503	−42.712%
	FDI	6890.364	10616.85	54.08%
Philippines	GF	0.891	1.14	27.95%
	GDP	480.604	462.667	−3.732%
	RDI	36.265	51.89	43.09%
	CO2	84.9	58.174	−31.479%
	FDI	1683.316	3269.671	94.24%
Singapore	GF	11.972	8.941	−25.317%
	GDP	5145.886	5007.888	−2.681%
	RDI	115.018	132.678	15.35%
	CO2	349.292	320.563	−8.224%
	FDI	32597.64	58056.81	78.10%
Thailand	GF	2.906	4.12	41.78%
	GDP	1170.744	1958.152	67.26%
	RDI	93.078	125.033	34.33%
	CO2	120.268	97.929	−18.574%
	FDI	3544.442	6199.191	74.90%
Vietnam	GF	0.757	2.002	164.46%
	GDP	379.546	663.076	74.70%
	RDI	39.29	133.923	240.86%
	CO2	111.955	209.323	86.97%
	FDI	804.198	2655.768	230.24%

Authors' calculations from the World Development Indicator's data.

Malaysia's (42.712%), and the Philippines' (31.479%). Thailand and Singapore's foreign direct investment (FDI) decreased by 8.574% and 8.224% from 2001 to 2020. An 86.770% increase in the FDI index for Vietnam, Cambodia and Brunei Darussalam, respectively. However, according to current data, Singapore is the most open economy in the ASEAN region, while Indonesia is the most closed economy.

Only Brunei Darussalam saw a decrease in environmental sustainability of more than 15% between 2012 and 2019. Singapore's environmental sustainability is US$ 58,056.810 (in constant terms), while Brunei Darussalam's is US$ 30,717.950 (in constant terms) (in constant terms). There is also a reasonable level of environmental sustainability in Malaysia and Thailand. Vietnam and Cambodia have both made significant progress in environmental sustainability. ASEAN member economies Vietnam and Cambodia have the lowest environmental sustainability.

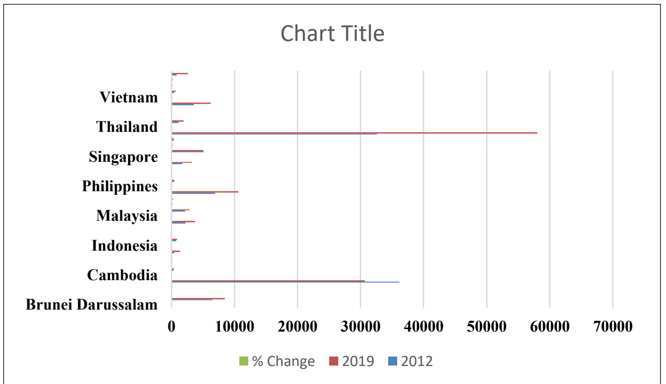

FIGURE 1 | % age Changes in the Association of Southeast Asian Nations selected variables between 2012 and 2020.

The % change in the selected ASEAN economic variables is shown in **Figure 1**. Changes in Cambodia's financial progress aren't shown because of the data's high observed value.

Model Specifications

The FMOLS and VECM methodologies are used to determine the impact of green finance on a clean environment and environmental sustainability. Control variables in the model include progress in the foreign direct investment, R&D investment and human development index. Studies such as Ahmad B. et al. (2021), Gao et al. (2021) and others show that financial development and an increase in population (Pop) lead to an increase in CO2 emissions, which is consistent with the findings of previous studies. According to the model's general specifications:

$$CO2 = F(GF, GDP, RDI, FDI, GRT, HCI) \quad (1)$$

Vector Error Correction Modeling

Because of the co-integration of their estimates, it was possible to create a casualty among variables in this study. This, as well as long-term inference, was accomplished through the application of VECM techniques based on Engle and Granger (1987) two-step procedures. **Table 2** in the findings section shows the economic performance of the Association of Southeast Asian Nations (ASEAN) in probit and logit terms. The energy efficiency of the countries under consideration in this study is unlikely to be adversely affected by Access or Enimp. It is projected that foreign direct investment (FDI) will play a role in the economic output of ASEAN countries. This is demonstrated by a rise in Chinese investment in the economies of the Association of Southeast Asian Nations. Almost all of China's and ASEAN's investments are in energy and transportation, with a little amount in other industries. The total amount of energy produced by ASEAN

TABLE 4 | Unit root test.

		Level				First Difference			
		Intercept		Intercept and Trend		Intercept		Intercept and Trend	
		Statistic	*P*-values	Statistic	*P*-values	Statistic	*P*-values	Statistic	*P*-values
GF	LLC	−1.652	0.115	−0.527	0.242	−5.870	0.000	−4.668	0.000
	IPS	−1.310	0.236	−0.807	0.722	−8.716	0.000	−8.105	0.000
	ADF	40.851	0.113	23.187	0.578	135.617	0.000	119.891	0.000
	PP	78.533	0.275	40.894	0.025	253.255	0.000	655.081	0.000
RDI	LLC	−0.031	0.428	−1.066	0.781	1.250	0.000	−0.787	0.000
	IPS	−5.439	0.880	−3.190	0.880	4.516	0.000	−4.339	0.000
	ADF	11.711	0.877	17.711	0.804	74.568	0.000	67.074	0.000
	PP	7.306	0.880	12.349	0.875	162.105	0.000	155.214	0.000
CO2	LLC	−1.748	0.285	−0.099	0.401	7.031	0.000	−5.953	0.000
	IPS	−1.054	0.778	−1.958	0.869	9.584	0.000	9.407	0.000
	ADF	21.573	0.658	17.877	0.799	148.808	0.000	136.550	0.000
	PP	35.490	0.175	39.283	0.037	287.478	0.000	854.190	0.000
GRT	LLC	−3.702	0.188	−2.105	0.007	−8.260	0.000	−7.631	0.000
	IPS	−0.095	0.402	−0.750	0.173	8.419	0.000	7.429	0.000
	ADF	28.091	0.327	30.695	0.217	128.533	0.000	107.175	0.000
	PP	53.164	0.275	37.908	0.051	195.967	0.000	173.967	0.000
HCI	LLC	−3.155	0.475	4.255	0.000	9.930	0.000	−8.056	0.000
	IPS	−0.163	0.375	3.103	0.000	9.808	0.000	−8.117	0.000
	ADF	30.135	0.239	52.318	0.001	151.870	0.000	117.058	0.000
	PP	29.444	0.267	34.210	0.113	246.523	0.000	210.804	0.000
FDI	LLC	−1.504	0.038	0.115	0.394	−6.533	0.000	−5.537	0.000
	IPS	−0.798	0.720	1.309	0.820	6.714	0.000	5.429	0.000
	ADF	17.788	0.802	16.431	0.833	101.235	0.000	80.760	0.000
	PP	15.374	0.851	10.834	0.878	173.430	0.000	147.233	0.000

countries. According to all characteristics, the ASEAN countries with the highest average energy absorption consumption. The VECM technique, which stands for long-term interaction of components, is used to examine how components interact over time. It is possible that the VECM demonstrates short-term causation, but the error correcting word ECT may demonstrate long-term causation eq. (1). Because of this, the VECM equation for economic growth (Y) looks like the following.

$$CO2_{it} = \beta_0 + \beta_1 GF_{it} + \beta_2 RDI_{it} + \beta_3 HCI_{it} + \beta_4 FDI_{it} + \beta_5 GDP_{it} + \in_{it}$$

$$\text{Where } \boldsymbol{i = 1, \ldots, N} \text{ and } \boldsymbol{T = 1, \ldots, T} \quad (2)$$

In order to estimate Eq. (2), we employ an econometric methodology that is divided into three parts. The first step entails determining the degree of integration of each variable that has been employed. Several statistical tests are employed in the econometric literature to determine the degree of integration of a variable. The following are some examples: These are the tests that will be used in this study: Dickey-Fuller Augmenté (ADF); and Phillips-Perron (PP). The next stage will be to investigate the possibility of cointegration relationships between the variables, which may occur over a lengthy period of time once the integration order of the series has been determined for each of the variables. This analysis will be carried out in accordance with the Pedroni test technique. The third stage is concerned with the testing of causality between the variables in the model. The so-called sequential test technique as well as the non-sequential vector error correction model (VECM) procedure will be used in this investigation.

RESULTS AND DISCUSSION

Unit Root and Co-integration Test

The findings of the ADF and PP unit root tests are presented in **Table 4**. The findings show no correlation between CO2 emissions, green finance, economic development, FDI, and R&D investment. At this level, these factors are not stable. At 1% and 10%, the degree of significance of clean energy investment and the human capital index is stable. However, when these variables were translated into the first difference, they became stationary at various significance levels. Economic growth and FDI are significant at 10%, CO2 emission at 5%, sustainable environment (SE), clean energy (CE), financial development, and R&D at 1% significance levels, respectively. At both the level and the first difference, clean energy investment and inflation (INF) remain stationary. As a whole, these findings show a mixed bag of happiness, with some factors being I (0), some being I (1), and none being I (). (2).

TABLE 5 | Co-integration results.

	(1)		(2)		(3)		(4)	
	Coeff.	**Significance**	**Coeff.**	**Significance**	**Coeff.**	**Significance**	**Coeff**	**Significance**
Within-dimension								
V-statistic	5.21	(0.000)*	11.49	(0.000)*	10.65	(0.000)*	32.04	(0.000)*
rho-statistic	−7.74	(0.000)*	10.87	(0.000)*	17.17	(0.000)*	22.31	(0.000)*
PP-statistic	−23.76	(0.000)*	10.65	(0.000)*	14.57	(0.000)*	46.01	(0.000)*
ADF-statistic	17.8	(0.000)*	14.18	(0.000)*	20.69	(0.000)*	25.16	(0.000)*
P-Weighted	14.67	(0.000)*	4.39	(0.000)*	12.03	(0.000)*	19.15	(0.000)*
Rho-Weighted	−9.41	(0.000)*	15.46	(0.000)*	19.4	(0.000)*	19.95	(0.000)*
PP-Weighted	14.9	(0.000)*	17.12	(0.000)*	22.89	(0.000)*	15.79	(0.000)*
ADF-Weighted	10.12	(0.4729)	13.06	(0.000)*	31.15	(0.000)*	8.03	(0.000)*
Between-dimension								
Group rho-statistic	2.01	(0.8542)	2.04	(0.7932)	2.00	(0.05819)	2.02	(0.6643)
Group PP-statistic	−2.18	(0.3287)*	−3.47	(0.7932)	−4.94	(0.0000)*	−2.10	(0.2199)*
Group ADF-statistic	−2.29	(0.3496)*	−4.61	(0.6819)*	−4.07	(0.0000)*	−2.18	(0.2018)*

** = p < 0.1.*

Table 5 shows the results of Kao's residual panel cointegration test (ADF). At the significance threshold of one %, we may reject the original hypothesis that there is no cointegration relationship based on the *p*-Value of 0.0069, which is far less than 0.01. Green finance and clean energy consumption have a significant impact on environmental sustainability. Therefore we can apply a Granger causality test to analyze the link between carbon emissions, economic growth, and green finance.

Long-Run Estimation

Table 6 shows the long-run estimates of FMOLS and robust least squares for each of the two study models independently.

TABLE 6 | Results of long-run estimations.

Variable	GF	RDI	GRT	HCI	FDI	GDP
Brunei	−0.064**	−0.084***	−0.941**	−0.019**	0.263**	0.263***
	(0.358)	(0.000)	(0.008)	(0.021)	(0.019)	(0.002)
Cambodia	−0.088*	−0.067***	−0.425***	−0.048*	0.064**	0.068***
	(0.057)	(0.001)	(0.000)	(0.054)	(0.035)	(0.009)
Indonesia	−0.176**	−0.152***	−0.207**	−0.102**	0.391**	0.391***
	(0.049)	(0.000)	(0.036)	(0.018)	(0.048)	(0.008)
Malaysia	−0.036***	−0.098***	−0.203**	0.072*	0.273**	0.273***
	(0.003)	(0.001)	(0.025)	(0.072)	(0.032)	(0.002)
Philippines	−0.089*	−0.083***	−0.793***	−0.223***	0.454***	0.454***
	(0.079)	(0.002)	(0.002)	(0.002)	(0.000)	(0.000)
Singapore	−0.132***	−0.065***	−2.741***	−0.014***	0.538***	0.538***
	(0.001)	(0.001)	(0.000)	(0.003)	(0.001)	(0.001)
Thailand	−0.024***	−0.277***	−0.183**	−0.107*	0.426***	0.426***
	(0.001)	(0.000)	(0.027)	(0.052)	(0.003)	(0.003)
Vietnam	−0.027**	−0.192***	−1.302***	0.276***	0.124***	0.124***
	(0.014)	(0.000)	(0.000)	(0.001)	(0.002)	(0.005)
Panel	−0.129**	−0.133***	−0.26*	−0.155*	−0.075**	0.778***
	(0.014)	(0.000)	(0.052)	(0.073)	(0.015)	(0.001)

, **, and * shows level of significance at 10%, 5%, and 1% level of confidence interval.*

According to the study results, while renewable energy investment has a negative impact on CO2 emissions and ecological footprint, it has a favorable impact on ASEAN's economic growth. Human capital development index, population, and FDI growth are linked to a reduction in CO2 emissions, a more sustainable natural environment, and increased economic development in the ASEAN region.

Multiple caveats apply to the findings' interpretation. Starting with a territorial perspective on environmental and resource concerns, the index shows whether nations meet science-based environmental requirements. Environmental norms are shown to be breached, but the index's indicators cannot reflect the severity of these violations. A good example of this is the outdoor air pollution indicator, which shows how much of the population is exposed to PM2.5 concentrations that are higher than the WHO's recommended levels. Norm 75 might theoretically be obtained in two countries where one-quarter of the population is subject to pollution levels above environmental standards. At the same time, the other quarter is exposed to pollution concentrations many times greater than the following criteria. As a result, the index's measures have a territorial rather than a consumption-based perspective. A different perspective might be provided by looking at usage metrics instead.

Vector Error Correction Modeling Model

These estimators established a long-term, well-balanced link between the two series. According to the VECM model, GDP significantly impacted ASEAN's CO2 emissions. The strong correlation between GDP growth and CO2 emissions predicts that a 1% increase in GDP will result in a 0.01926% increase in CO2 emissions. The findings of this study are significant, and higher growth rates can result in CO2 emissions. As a result, GDP positively impacts CO2 emissions but was statistically insignificant in the FMOLS estimator (**Table 7**). According to the VECM estimate, an increase in GDP was accompanied by an increase in the country's primary production components, including labor, capital, and land. To run these businesses, large

TABLE 7 | Casualty test.

	CO2	GF	RDI	GRT	HCI	FDI	GDP	ECT_1
CO2	–	0.138	0.385	0.032	0.199	0.039*	0.159***	0.039
	–	(0.228)	(0.184)	(0.120)	(0.226)	(0.075)	(0.007)	(0.121)
GF	0.080**	–	0.012**	0.060***	0.043*	0.030**	0.036**	0.067***
	(0.012)	–	(0.042)	(0.005)	(0.051)	(0.017)	(0.029)	(0.002)
RDI	0.015**	0.025*	–	0.084***	0.136*	0.059**	0.076**	0.026***
	(0.014)	(0.050)	–	(0.005)	(0.059)	(0.020)	(0.033)	(0.002)
GRT	0.607**	1.258	0.136	–	0.663	0.134	0.548*	0.040***
	(0.013)	(0.587)	(0.472)	–	(0.580)	(0.199)	(0.060)	(0.000)
HCI	0.021**	0.017**	0.133**	0.054	–	0.078**	0.071*	0.055***
	(0.012)	(0.042)	(0.042)	(0.105)	–	(0.017)	(0.076)	(0.002)
FDI	0.039**	0.226	0.139	0.042**	0.230**	–	0.159*	0.024***
	(0.031)	(0.141)	(0.124)	(0.013)	(0.015)	–	(0.053)	(0.001)
GDP	0.047**	0.081	0.198	0.059**	0.126	0.042**	–	0.044**
	(0.013)	(0.139)	(0.113)	(0.043)	(0.112)	(0.037)	–	(0.042)

** = $p < 0.1$, ** = $p < 0.05$, *** = $p < 0.01$.*

volumes of polluting energy must be used, which contributes to the emission of CO2. They support previous studies by Ortega-Arriaga et al. (2021), Sinha et al. (2021), who discovered the link between economic growth and CO2 emissions. We find that GDP is not a significant long-term driver of CO2 emissions, as previously proposed by Khan and Chaudhry (2021).

The study's findings show that green finance significantly impacts carbon dioxide emissions. An increase in GF will raise emissions by 0.3516% and 0.31094%, respectively, according to estimates from the VECM and FMOLS models. As most ASEAN countries are surrounded by businesses that rely heavily on polluting energy sources, this result is not surprising. Thus, economic activity in ASEAN countries is linked to the large-scale use of unfavorable energy sources, such as coal, natural gas, and the like. This conclusion shows. The country's emission rate rises as a result of these sources of energy. CO2 emissions in the countries are increased when there is an increase in the processing of goods and services, which is linked to the consumption of large quantities of fossil fuels. According to Tang et al. (2022), environmental sustainability is significantly driven by CO2 emissions, consistent with our findings. On the other hand, opposing our results, Fu et al. (2021) revealed that GF does not influence CO2 emissions, while Sun et al. (2021) discovered an opposite relationship between GF and CO2 emissions, signifying that increasing concept of green finance reduces CO2 emissions.

Both VECM and FMOLS found that FDI had no impact on ASEAN's CO2 emissions. As shown by the lack of significance of FDI's impact on CO2 emissions, an increase in FDI in ASEAN countries has little effect on those countries' emissions. According to this study, people moving to municipalities, which leads to enhanced industrialization, firms' development, and the formation of roads, hospitals, bridges, and markets, do not affect CO2 emissions. Dong et al. (2021), as well as Salari et al. (2021), all found Inflation (INF) to be a minor source of CO2 emissions. Our findings corroborated theirs. An earlier study by Fu et al. (2021), Khan and Chaudhry (2021), Tang et al. (2022) found that foreign direct investment (FDI) is an important predictor of greenhouse gas emissions.

In the past decade, ASEAN's green finance has grown significantly, and the overall trend of green finance is positive, according to the ASEAN's green finance composite index. Overall economic growth increased from 0.2242 to 0.8943, demonstrating that ASEAN's economy has done well in recent years and has continued to develop. From 0.2077 to 0.8693, the average composite index shows an increasing trend. The robustness economic growth function is larger than the comprehensive index of green finance, demonstrating that an effective development mechanism has been established between the two.

Discussion

Research on a green premium finds a divided but somewhat positive consensus in the primary ASEAN market. To put it another way, investors are willing to pay more for GF and accept a lower yield in return. Issuers and the growth of the Bitcoin market will benefit from these findings. The GF market may help governments fund zero carbon projects at a lower cost, particularly for bonds that a third party can verify. As more companies learn about the benefits of the green premium, the GF market is expanding. According to this study, non-economic considerations, such as environmental concerns, should be considered when defining bond pricing in the future (Yumei et al., 2021). Green investments, green financing policies, and green financing tools can all benefit from it (such as green bonds). To get the best potential choices for policymakers, further research into this area is timely, pertinent, and of great attention, paying particular attention to the energy sector's transition and conducting theoretical and empirical debates on the current opportunities and obstacles. These numbers are not insignificant compared to what the Green Climate Fund has raised thus far.

These findings would be altered if different assumptions were made about long-term trends in global GDP, oil prices, and oil supply. However, estimates based on crude oil export taxes give a rough idea of how much revenue could be generated. Mobilizing financial capital for energy efficiency creativities is crucial to combat climate change and meet the rapidly increasing energy requirement. Renewable energy investors face a number of obstacles when it comes to pursuing efficiency and efficiency investments. Therefore green bonds offer a novel way to raise money for both types of projects. The amount of green investment needed to reach this level will increase by 400%. Green bonds may be able to cover this gap in investor assets. A growing number of people are investing in green bonds. The number of countries issuing green bonds is also on the upswing. The Indonesian government has issued around half of the world's green bonds. It is estimated that green building projects account for more than half of the total invested in green bonds worldwide. In contrast, clean energy production accounts for most of the total invested. In order to attract more investors to green bonds, ASEAN's offered incentives to bond issuers to cover the costs of third-party audits. Many of ASEAN's award recipients were first-time issuers drawn to the grant program by regulations that lower the cost of green bond issuing (Zhang et al., 2022).

This analysis concludes that the green credit policy is part of the financial sector's efforts to promote renewable energy investment. An investigation of the impact of green practices in the form of credit cards and the conditions of credit issuance encourages investment in renewable energy businesses. Eco-friendly renewable energy companies will benefit from this financial aid. It has been shown that green practices in the development of credit cards and credit policies have a significant impact on renewable energy because their major goal is to encourage eco-friendly enterprises. When COVID-19 was in effect, the green securities policy, whether to issue equity or debt securities, significantly influenced investment in renewable energy firms (Xiong and Sun, 2022). Jin et al. (2021) found that investments in renewable energy companies that aim to reduce environmental consequences are encouraged by applying green components in financial securities policies. According to Zhao et al. (2021), the environmental performance of different economic sectors shows that green financial securities have a huge impact on renewable energy project expansion.

The standard of living for humans has been raised thanks to new and creative attempts to improve the environment (Sun et al., 2021). A slow-moving environmental issue, the global financial crisis, can be compared to COVID, a fast-moving and highly stimulated one (Coscieme et al., 2021). In addition to being harmful, this pandemic's effects on society are worrying. In the post-pandemic era, the gap between supply and demand has widened more than ever before (de Lorena Diniz Chaves et al., 2021). Energy, food, and water scarcity have long been seen as a burden on economies, but the recent rise in health-related concerns has exacerbated this problem. The well-being of society necessitates efforts that are both economical and environmentally beneficial, as well as healthy in terms of protection (Vujanović et al., 2021). In light of the COVID-19 lockout, green financing is being hailed as a possible solution to the global environmental crisis exacerbated by the widespread usage of renewable energy.

COVID-19 has had a profound effect on the economy and industry. Previous years' corporate and economic problems have been significant, but this virus has utterly destroyed everything. Small businesses are constrained. As a result of the suspension of cross-continental travel and commerce, the economies of all countries have collapsed. COVID-19 is both a medical and financial emergency (Meseguer-Sánchez et al., 2021). Viruses like this one have a devastating effect on businesses. Millions of people worldwide have died as a result of a lack of vaccinations and other preventative medications. All individuals throughout the world have been affected by this pandemic. Employees and employers are increasingly concerned about health-related risks and insurance. Sanitation and the precautionary measures that go along with it have had a profound impact on every industry (Li et al., 2021). Nowadays, workers are more concerned about the cleanliness and health of their workplaces. The only way to combat this global issue is through better planning and the development of less demanding infrastructure on the planet's resources. Everyone has to break into the business world these days. Creating a green economy is now the only way to run businesses resource-efficient and elegant. Policymakers are developing new and innovative strategies in developed countries to go along with environmentally friendly approaches and COVID-19 preventive treatment options (Tao et al., 2021).

It has also been shown that various insurers' introduction of green investment strategies has positively impacted green finance investment. According to D'Amato et al. (2021), a study of green finance in developing economies, renewable energy schemes are being monetarily supported by insurers committed to environmental security. The outcomes are also in line with (Shah et al., 2022)'s literary works, which attempt to intricate the role of green investment in finance in enabling the formation of renewable energy companies and enhancing their environmental performance. This study's outcomes also show that green investment is a strategy for environmentally friendly financial development that continues to promote the use of renewable energy sources even during the COVID-19 period. The goal of green investment is to place funds into environmentally friendly projects. These findings align with previous research by Alataş (2021), which found that providing renewable energy companies with a solid financial foundation improves their performance and encourages economic investment in environmentally friendly projects. A study by Greenfeld et al. (2021) indicated that green economic development contributes significantly to the financial resources of renewable energy firms because of their shared purpose of preserving the environment.

A further study indicated that the corporate social responsibility report published by different corporations, as observed during the pandemic of COVID-19, has a favorable link with investment in renewable energy projects. In agreement with previous research by Zhong et al. (2022), these findings support the hypothesis being advanced. Corporate social responsibility (CSR) reports emphasize the importance of environmental sustainability, so companies invest in renewable energy projects to reduce emissions of hazardous gasses and chemicals by recycling energy resources. These reports are the basis for these studies. A study published by Singh et al. (2021) found that the publication of a business organization's social responsibility report on a regular basis increases investment in companies that can generate renewable energy and reduce pollution. Finally, the research results show that investments in renewable energy have a favorable impact on economic growth. The findings of Iqbal S. et al. (2021) are consistent with this study. According to this theory, while an economy is developing, all sectors of the economy can invest in initiatives like renewable energy projects that are helpful to their long-term viability.

Innovative business plans necessitate CSR reporting (Can et al., 2021). Every economy relies on the banking sector. Pakistan's economy is on the verge of collapse, and corruption is the primary culprit (Nabeeh et al., 2021). Corrupt politicians have damaged the Pakistani economy. It is critical that businesses engage in CSR activities (Moussavi et al., 2021). In Pakistan, air pollution is a significant threat. Pakistan is plagued by air, water, and noise pollution (Wiseman et al., 2022). Innovative business planning strategies are required from all policymakers in order to ensure a stable and prosperous economy. It is possible to improve the environment's health by using environmentally friendly raw materials in factories and waste management programs. Financial difficulties can be overcome with sincere and well-coordinated efforts from people from all walks of life.

CONCLUSION AND POLICY IMPLICATIONS

Green finance, economic growth, energy consumption, and foreign direct investment (FDI) have been studied extensively, but the ASEAN region has received little attention. There is a dearth of a composite metric to describe the entire environmental performance; instead, CO2 emissions are employed as a proxy for environmental quality in earlier studies. This study adds to the growing knowledge on green finance and economic growth, research and development, FDI, green technology innovation, and sustainable development. It also focuses on the ASEAN region. Empirical analyses have also included VECM and FMOLS estimators.

According to research, ecological performance has been shown to improve as a result of green financing. Furthermore, economic expansion has been demonstrated to impact the environment positively. Despite this, ASEAN countries' environmental performance is deteriorating due to increased energy consumption and foreign direct investment. The study's findings show that ASEAN financial institutions have lent money to environmentally conscious companies. According to our findings, environmental performance in ASEAN can be improved through the development and implementation of more focused policies and green financing. As a result, the governments of these countries should lend more money to environmentally beneficial and energy-efficient initiatives in the future. Other developing countries around the world should also provide recognition to environmentally and energy-conserving projects. According to the SDGs, this might help accomplish sustainable development and environmental-related goals (SDGs) in 2030. In addition, policymakers should devise policies that sustainably promote economic growth, improving overall environmental performance. Nevertheless, since energy use degrades environmental performance, emerging economies should reduce and regulate their resource usage. To reduce greenhouse gas emissions caused by nonrenewable energy consumption, this study recommends that ASEAN countries in particular and other developing countries, in general, promote renewable energy for the manufacture of goods and home use. Furthermore, the region should support eco-friendly and energy-efficient technology to produce the same amount of goods and services with less energy.

Practical Implications

Reducing human economic activity's detrimental externality necessitates global action. Proponents claim that green finance is a critical tool for reducing negative economic consequences while fostering strong economic growth. We advocate the following policies based on the negative association between green finance and CO2 emissions.

1. To encourage the growth of green finance, the ASEAN should implement regulations that use fiscal resources to direct credit funding and social capital into eco-friendly investments, credits, and securities.
2. The government must develop a more efficient and effective green funding system and prioritize green operations in the approval process.
3. Lowered issuance and trading thresholds for eco-friendly securities should be part of government policy in ASEAN undeveloped countries.
4. ASEAN countries should use green financing to raise money to improve the environment.

Directions for Future Research

In order to attract more investment, our study might be expanded to look at the expansion of green finance into other financial markets from a portfolio viewpoint.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

Both authors listed have made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

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Assessing the Role of Green Finance and Education as New Determinants to Mitigate Energy Poverty

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Energy poverty (EP) is a problem that affects developed and developing economies, and its mitigation is of great significance to social welfare. EP affects Latin American countries, and policymakers have recently attempted to address this issue, particularly in the aftermath of the recent economic crisis. It is essential to measure and evaluate EP to implement strategies and policies effectively. Using a panel quantile regression approach, we investigate the heterogeneous impact of green finance, renewable energy (RE), and energy efficiency (EE) on EP for 33 Latin American countries from 2000 to 2018. Furthermore, certain associated control variables are incorporated into our model to avoid an omitted variable bias. According to empirical results, the impact of independent variables on EP is heterogeneous. Specifically, green finance is an essential source of alleviating EP, and it has a significant positive effect across all quantiles, but it is especially strong in the middle quantiles. RE and EE significantly mitigate EP, with the strongest effects occurring at higher quantiles. By including green finance, RE, and EE as the main explanatory determinants of EP, the findings urge policymakers in Latin American countries to design a comprehensive energy conservation policy to minimize the effects of massive EP.

Keywords: energy poverty, green finance, renewable energy, energy efficiency, panel quantile regression, Latin American countries

INTRODUCTION

The global energy system is facing severe challenges due to widespread energy poverty (EP) worldwide. EP is described as a lack of sufficient, inexpensive, high-quality energy to meet a family's development and survival needs (Adebayo et al., 2022a). It's marked by high energy costs in affluent countries and a lack of modern energy access in poor countries (Adebayo, 2022a). EP is a considerable danger to long-term development, health, and education, and it has gotten a lot of attention recently. The United Nations (UNs) published Sustainable Energy for All in 2001 to address the issue of worldwide EP (Irfan et al., 2022; Wen et al., 2022; Xiang et al., 2022). Goal 7 of the Sustainable Development Goals (SDGs) is to provide sustainable, modern, reliable, and affordable energy to everyone by 2030. Indoor air pollution caused by solid fuel usage has long been a concern for the World Health Organization (WHO). The World Bank is working to promote environmentally friendly cooking techniques and contemporary fuels (Khokhar et al., 2020; Iqbal et al., 2021; Feng et al., 2022). The European Commission recommends establishing the European Union Energy Poverty Observatory to aid its members in eradicating EP. EP must be addressed as soon as possible by enacting standard policies, which necessitate a complete investigation of global EP.

Poverty reduction is a multifaceted notion that includes more than just income poverty. On the other hand, existing research remains optimistic about the effect of Green finance on reducing EP, even though it can promote education and health, and income growth. As a result, the expansion of the financial sector as a channel for financial services and fund transfer might have a substantial effect on EP *via* the two main channels: (1) electricity or energy production; (2) electricity or energy consumption. Green finance can help alleviate EP by giving residents the means to purchase electricity, renewable fuels, and technologies (Asbahi et al., 2019; Iqbal et al., 2020; Huang et al., 2022). The financial sector's development can also help finance the shift from fossil fuels to renewable energy (RE) sources. Green finance is essential for raising finances for power producers in the energy/power sector. It has the potential to increase power output and alleviate EP. To put it another way, Green finance can help alleviate EP. Financial liquidity or depth and the size of the market; the ability of individuals or financial access and businesses to obtain financial efficiency, and financial services or institutions' ability to get financial services are all three dimensions of Green finance, according to the literature (Yu et al., 2022). The ability to deliver financial services at a cheap cost, with a long-term income stream and a vibrant capital market. In other words, fiscal access may be critical for reducing EP on the demand side (access to energy and power). On the other hand, the supply side prioritizes financial depth and financial efficiency (electricity production).

This study aims to investigate the green finance and education expenditure on EP. In many ways, our research contributes to the body of knowledge. It offers a detailed empirical analysis of how green finance, RE, and energy efficiency (EE) affect EP at the country level. The research adds to the few studies that have previously focused on EE, income, and energy prices as the fundamental causes of EP in developed nations. Boardman et al. (2013), for example, uses data from European countries to investigate the factors that contribute to fuel poverty (poor-quality housing, high fuel prices, and low incomes). Francisco et al. (2015) uses the Australian Household, Labour Dynamics, and Income Survey data to investigate Australian households' fuel poverty experience and energy expenditure. Churchill and Smyth (2020) use data from 13 waves of representative longitudinal data for the Australian adult population to investigate the link between self-assessed health and EP. This research makes an important addition since it deviates from the traditional focus on developing nations, investigates a new factor of EP, and gives solid evidence for Latin American countries with high EP rates. The findings are particularly important for policymakers since they highlight the role that Green finance can play in decreasing EP and creating policies to improve the transition processes of households' energy and sustainably mitigate EP.

Rest of the study is organized as follows: section "Literature Review" provides the literature review, section "Method and Data" discuss the theoretical framework of the study, section analyze the results and finaly section "Conclusion and Policy Recommendation" provides the conclusion and policy recommendations.

LITERATURE REVIEW

Energy Poverty

Reddy et al. (2000) define EP as the absence of sufficient choice in accessing adequate (Adebayo, 2022b), affordable (Awosusi et al., 2022), reliable (Fareed et al., 2022), high-quality, safe, and environmentally benign energy services to support economic and human development. Socioeconomic development is greatly enhanced when having clean, inexpensive, constant, and modern energy resources and is also connected the achieving the sustainable development goals (SDGs), specifically the SDGs no hunger, poverty, good health, gender equality, well-being, weather action, and land existence (see Ntaintasis et al., 2019; Bienvenido-Huertas et al., 2020; Awaworyi Churchill and Smyth, 2021a). Considering how expensive clean and modern fuels are, coupled with the low buying energy in third-world countries, such advantages have affected the government efforts in expediting families' transformation from using conventional to modern fuels for lightening and cooking (Adebayo et al., 2022b). Almost 2.5 billion people globally rely on traditional biomass for cooking food. About 120 million human beings use kerosene, even as 127 million humans use coal (Nduka, 2021). Moreover, the first time IEA assessed EP was in the World Energy Outlook Report in 2002. However, this assessment has recently been changed. The United Nations General Assembly has designated 2014–2024 as a decade of sustainable energy. The scope of EP appears to be a research gap, which can be filled by assessing EP using a set of comprehensive indicators. This makes it easier to implement effective policy solutions to the problem. Researchers have conducted several studies, but the clues are limited. Therefore, the severity of this problem can be misinterpreted as a degree.

Previous research has used a variety of EP measurements in various contexts, which are mainly based on data availability, as one of the first studies of EP in India (Pachauri et al., 2004) assesses EP in India based on access to various energy types and levels of energy consumption. Access to electricity is used as a measure by Castaño-Rosa et al. (2020) in a study of Spain and Ye and Koch (2021) in South Africa. According to Indrawan et al. (2020), approximately 1.6 billion people worldwide lack access to modern energy fuels. In a study of Bangladesh (Moniruzzaman and Day, 2020), employs the same measure. In Pakistan (Qurat-ul-Ann and Mirza, 2021), focus on access to modern cooking technologies. Setyowati (2020) looks at Indonesia's point where energy consumption rises as household income rises. In the case of the Philippines (Bertheau, 2020) take a similar approach. Recent studies vary in their choice of an EP proxy (Karpinska and Śmiech, 2021; Rodriguez-Alvarez et al., 2021; Igawa and Managi, 2022).

Green Finance and Energy Poverty Nexus

Countries with high unemployment and low incomes demand policy options that can accelerate household energy transitions and thus alleviate EP on a long-term basis (Koomson et al., 2020). Green finance may be one of the possible channels. Green finance is widely recognized to alleviate poverty, reduce the likelihood of future poverty, and improve economic well-being and welfare. According to economic theories, Green finance is one of the most important drivers of economic development because of its crucial functions in providing financial services and transferring funds. Through this, Green finance is an important part of framing institutions. Financial sector improvement may have an insightful impact on EP in supply and demand. Financial sector development is critical for fund generation and electricity supply. Previous research (Sadorsky, 2010; Mahalik et al., 2017; Khan et al., 2020) found that Green finance could increase energy consumption.

Moreover, the development of the financial sector provides funding for people as a part of the energy transition to clean energy, biomass cooking, and heating technologies. For example (Shahbaz et al., 2022), demonstrate that the financial sector's development is an important factor in RE deployment. In terms of energy production, the financial sector has a crucial position in the energy sector (Alsagr and van Hemmen, 2021). The cost of energy production, particularly electricity generation and transmission, is enormous. This is extremely difficult in developing countries, and it is considered a financial constraint. Green finance can provide help in developing the process of electricity production and transmitting and delivering electricity to more citizens. In other words, Green finance is expected to alleviate EP on both sides.

Theoretically, Green finance is a way the transferring financial services and funds. It will have an impact on EP through production and energy use (Ahmad et al., 2021). First, the Green finance level provides the funds for transforming energy and greener technologies (EE). Second, through credit and funds, it will be possible to provide households with essential access to electricity, technologies, and clean fuel. Specifically, by helping consumers and producers to generate finances, financial aid contributes to overall poverty reduction through increased public awareness of EE, increased access to funds, and enhanced electricity generation (Shahbaz et al., 2021). The ability to obtain financial services is referred to as financial access, which is critical for reducing EP by increasing access to energy.

Apart from the household's socioeconomic characteristics and properties mentioned in the introduction, little literature investigates the association between EP and other determinants. Nguyen and Su (2022) assess the impact of Green finance on EP in 56 developing countries classified as upper-middle-income, low-middle income, and low income. Green finance, they claim, will help to control income energy prices, EE, and reduce EP. Moreover, they notice that per capita electricity consumption, technologies for cooking, access to clean fuels, and the Green finance index are strongly correlated. On the other hand, these authors focus on a global level analysis and ignore more detailed EP measurements and important household connections. Previously (Setyowati, 2020), argued that the financial sector's development would be essential for RE development to mitigate EP. Halkos and Gkampoura (2021) investigate the impact of poor-quality housing, high fuel prices, and low income on fuel poverty in a sample of European countries. Awaworyi Churchill and Smyth (2021a) discussed the impact of health self-assessment on EP and clarified the possible role of financial inclusion in mitigating EP.

Literature Gap

Several gaps can be identified from the literature reviewed in the previous subsections. First, it is clear that the existing literature overwhelmingly emphasizes the impact of financial development on EP, while only a few of the recently published studies have elucidated the relationship between financial inclusion and EP. More importantly, no previous research has attempted to examine the impact of financial development on EP using a panel dataset of Latin American countries. However, it is also relevant to decompose the analysis of different quantiles of EP using non-parametric methods. This study aims to bridge these literature gaps using relevant data and econometric methods from Latin American country's cases.

METHOD AND DATA

Econometric Techniques

This research uses the panel quantile regression (PQR) model to study the impact of Green finance, natural resources, and RE on EP in the panel of Latin American countries. PQR is used to examine the conditional distribution of the relationship between the variables of this research in various countries. Using traditional regression methods can result in an overestimation or an underestimation of the correlation coefficients, or it can fail in the successful detection of meaningful relationships since these methods' main concentration is average effects. Koenker and Bassett (1978) developed the PQR. The following is an example of how median regression analysis can be applied to other quintiles:

$$Q_{iy}\left(\tau/x_i\right) = x_i^T \beta_\tau \tag{1}$$

Quantile regression is more robust in heavy distributions, but it can't deal with unobserved country heterogeneity. As a result, the current study used panel quantile fixed effects to investigate conditional and unobserved individual heterogeneity. Quantile regression has been applied to panel data using econometric theory by Lamarche (2010) and Galvao (2011), as well as Koenker (2004). The following is an example of fixed-effect PQR:

$$Q_{iy}\left(\tau_k/\alpha_i x_{it}\right) = \alpha_i + x_{it}' \tau_k \tag{2}$$

Due to the problem of incidental parameters, PQR with fixed effects has a significant problem when there are a lot of fixed effects. There will be inconsistency when individuals reach infinity, but fixed observations for each cross-section will be made. The purpose of using fixed effects is to eliminate unobserved fixed effects. The fact of such theories is that the expectation is linear. That is no reason for a conditional quintile (Canay, 2011). In order to eliminate these types of issues (Koenker, 2004), suggested the proper method in which the author sets the unobservable fixed effect as a parameter and estimates it together with the independent variable impacts of various quintiles. In this technique, the calculation problem is minimized by using the estimated parameter penalty term, through which the parameter estimate is calculated as follows:

$$min_{(\alpha,\beta)} \sum_{k=1}^{k} \sum_{t=1}^{T} \sum_{i=1}^{N} \omega_k P_{\tau k}(y_{it} + \alpha_i - x_i^T \beta_\tau) + \lambda \sum_{I}^{N} |\alpha_i| \quad (3)$$

In the above formula, i represents the country index (N). The number of observations in the country is represented by T, which is the quantile index. The matrix of the explanatory variable is provided by x, where $P_{\tau k}$ is the quintile's loss function, W_k is the weight to the Kth quantile using for the contribution of Kth quantile controls on the fixed effect estimation. Current research focuses on equal weight quantiles $W_k = 1/K$ given by Alexander et al. (2011). In addition, λ represents an adjustment parameter whish helps estimating and reducing the individual consequence to zero. The term of penalty will disappear if λ approaches zero, and then the usual stable effects measuring tool can be obtained. Nevertheless, when the term tends to infinity, we will acquire model estimates without individual influence. The currently established role is equal to 1 (Damette and Delacote, 2012). The descriptions of the quintile function of the variables currently studied may be as follows:

$$Q_{iy}\left(\tau|\alpha_i, \xi_t, x_{it}\right) = \alpha_i + \xi_t + \beta_{it}GFI_{it} + \beta_{it}RE_{it} + \beta_{it}RE_{it} + \beta_{it\ it} \quad (4)$$

where, i represents the country, and the time is t, which are the indicators of emissions, sustainable power, and fiscal improvement in the equation. RE equals renewable energy, CO equals carbon dioxide emissions, GF equals Green finance, TO equals trade openness, FDI equals foreign direct investment, UP equals urban population, LBF equals labor, and MT equals the product in the model.

In order to estimate the panel data quantile regression model constructed in Equation 4, this research uses the panel data technique that considers cross-sectional dependence. Pesaran (2007) demonstrated that panel data analysis would show significant deviation and size distortion when the cross-sectional dependency is ignored. Therefore, before the parameter estimation preliminary test, first, check the cross-sectional dependence.

Panel cointegration, panel unit root, and cointegration estimators are used in the next step to determine the model's long-run relationship. It is first necessary to determine whether the series is stationary or not, as non-stationary series indicates the issue of spurious regression. Pesaran (2007) proposes a cross-sectionally augmented ADF (CADF) unit root test for observing stationary behaviors of variables that takes cross-sectional dependence into account. The cross-sectional IPS (CIPS) statistic is calculated by taking the arithmetic mean of individual CADF statistics calculated for each country in the panel. The CIPS test's null hypothesis assumes that the series has a unit root.

The result of this analysis shows that the series can be stationary at point [I(0)] or the first variation [I(1)]. When the sequence operates in a stationary procedure, the traditional OLS method is used to estimate the coefficients. Diversely, when the sequence acquires unit roots, the cointegration relationship (as long-term motion) must be verified before coefficient estimation. Westerlund (2008) proposed a DurbinHausman program to verify the viable cointegration relationship in panel data analysis. This method appraises cross-dependence and generates two data. First, the DurbinHausman process (hereinafter DHp) studies the long-term connection with the supposition of homogeneity. Second (hereinafter DHg), defines that connection under the condition of partial panel heterogeneity. The null hypothesis of the DHp and DHg tests means no cointegration.

When the cointegration relationship is defined, the long-term variables may be estimated. To this end, this study implemented the completely revised continous update estimator (CUPFM) and bias corrected continuous update (CUPBC) recommended by Bai and Kao (2006) and Bai (2009). First, Bai and Kao (2006) utilize this Equation 5. Consider the correlation between units through the introduction of ordinary factors as a matrix.

$$h_{it} = c_i + \acute{\gamma} m_{it} + e_{it} \quad (5)$$

Among them, the i dependent variable is represented by hit. The t unit period in the panel. c and \u03b3 represent the constant term and the coefficient matrix. mit and eit are the mean matrix of explanatory variables and error terms, respectively, which is composed of two section, as shown in Equation 6. Including series factor loading (\u03bbi) and unobserved factor (ft).

$$m_{it} = m_{i,t-1} + u_{it}, e_{it} = \acute{\gamma}_i f_t + \eta_{it} \quad (6)$$

Second (Omar and Hasanujzaman, 2021), made use of the FMOLS estimator which was suggested by Rao et al. (2022) in order to examine the existence of ordinary factors through equation has the coefficient \u03b3 estimated by Equation 7.

$$\overbrace{\gamma}\ FMOLS \quad (7)$$

In the first step, the residual error from each previous stage is used to repeat the estimation until merging. This iterative operation classifies as a CUPFM method. The process in Equation 6. Later modified by Bai (2009). Follow Equation 8.

$$m_{it} = m_{i,\,t-1} + u_{it}, f_t = f_{t-1} + \eta_t \quad (8)$$

Furthermore, Bai (2009) in order to correct for deviation directly in the estimate, they developed a deviation correction indicator, which they always did upgrade until convergence is illustrated. The process is referred to as a continuous update drift correction estimator (CUPBC). Bai (2009), a Monte Carlo experiment showed that CUPBC and CUPFM are significantly better than traditional estimators in all cases. Such indicators are

TABLE 1 | Descriptive statistics.

Variable	Min	Max	Mean	SD
GF	0.2944	0.3648	0.0032	0.0288
EDU	22.4	5004.8	304.2	742.6
INFS	18.56	100.8	45.76	15.712
URB	3.2	22.4	14	5.248
GDP	528.64	33999.68	5500.48	4308.96
EE	45.76	37.76	1.424	8.368
GovS	4.96	1543.52	148	216.32
T	48.48	765.28	227.04	93.44
NRES	99.2	2346.56	376.464	318.128

TABLE 2 | Results of CD test.

Variables	LM	CD_{LM}	LM_{adj}	CD
lnEP	495.72*** (0.000)	47.51*** (0.000)	47.24*** (0.000)	1.87*** (0.060)
lnGF	587.72*** (0.00)	57.20*** (0.000)	56.94*** (0.000)	23.27*** (0.000)
lnEE	869.72*** (0.000)	86.93*** (0.000)	86.67*** (0.000)	29.48*** (0.000)
lnEdu	553.19*** (0.000)	53.56*** (0.000)	53.30*** (0.000)	15.81*** (0.000)
lnInfs	648.28*** (0.000)	63.59*** (0.000)	63.32*** (0.000)	25.29*** (0.000)
lnU	339.04*** (0.000)	30.99*** (0.000)	30.73*** (0.000)	11.53*** (0.000)
lnT	869.72*** (0.000)	86.93*** (0.000)	86.67*** (0.000)	29.48*** (0.000)
lnRE	553.19*** (0.000)	53.56*** (0.000)	53.30*** (0.000)	15.81*** (0.000)
lnFDI	648.28*** (0.000)	63.59*** (0.000)	63.32*** (0.000)	25.29*** (0.000)
lnNR	339.04*** (0.000)	30.99*** (0.000)	30.73*** (0.000)	11.53*** (0.000)

1% level of significance.

persistent with inhibitory variables and endogenous problems, and have strong presence of factors and regressors I (1) and I (0).

The final step in the analysis used causality to test the viable two-way connection between GF and EP. The causality analysis, which was suggested by Dumitrescu and Hurlin (2012), takes into account cross-sectional reliance to uncover the feasible two-directional causal relationship in-between GF and EP. The null theory means that no causal connection exist between the variables.

Data Sources

In this study, we used panel data, which alleviates the problems associated with the limited time series available for the Green finance-EP nexus. When analyzing panel data, country-specific and heterogeneous effects can also be controlled. Based on data availability (2000–2018), our sample is limited to 33 Latin American countries (see **Table 1**). The variables used in this study are GDP per capita, EE, education expenditure, infrastructure expenditure, urbanization, technological innovation (R&D), renwable energy, and natural resources. The equations are estimated using data from the World Bank (2018). In order to explore the data, **Figure 1** clarifies how the data is distributed. We also provide descriptive statistics in **Table 1**. We interpolated some of the variables to keep the sample size under control and preserve the sample size. The variables selected for the analysis are converted to logarithms for final assessment. Finally, all the variables were differenced because the time taken was an average of 3 years, which is too short to test the reliability for unit roots. Estimation in differenced form avoids trend problems, and in most cases, the parameters in the first difference are more likely to be stationary.

RESULTS AND DISCUSSION

Cross-Sectional Dependence and Unit Root Test

The study employs panel data techniques that account for cross-sectional dependence. According to Pesaran (2006), when cross-sectional dependencies are not taken into account, panel data studies show size distortions and significant bias. Therefore, before performing the preliminary test of parameter estimation, first check the cross-sectional dependence. We utilized the Lagrange Multiplier (LM) test presented by Breusch and Breusch and Pagan (1980), the CDLM and CD test presented by Pesaran et al. (2004), and the deviation-adjusted LM test (LMadj) presented by Pesaran, Ullah and Yamagata (2008) to examine if there is dependenc. Such examinations study the null hypothesis of cross-sectional non-dependence opposed to other hypotheses that imply cross-sectional dependence does exist. To carry out the overall analytic steps mentioned in the previous section, the original code written by the Gauss 10 software and its developers was used.

The findings of the cross-sectional dependence test are shown in **Table 2**. Findings of the study show that at the 1% statistical significance level, the null hypothesis is rejected across all variables. The results indicate that a crisis in one of the world's most visited countries may have an impact on other variables. Concecunatly, using the second generation of panel data approaches to get strong conclusions, it is vital to examine the interdependence of countries.

In the following step, n order to find the long-term association in the model, we use panel cointegration, panel unit root and cointegration estimator. First of all, it is convenient to check whether the series is stationary, because the complication of false regression is revealed by non-stationary series. Pesaran (2007) proposed a cross-section-augmented ADF unit root test (CADF), which considers the correlation of the cross-section to observe the smooth behavior of variables and to obtain CIPS statistics.

Table 3 shows the outcomes of the IPS test presented and the aforementioned CIPS unit root test (transversal IPS), which constitute the first-generation and second-generation units, respectively. In accordance with the IPS test results, URB is stable at this level, even though other variables have unit roots. In the CIPS test, for all variables, the null hypothesis is not rejected, which means that all variables have unit roots. However, these variables become stable after taking the first difference. Before estimating long-run coefficients that would disclose the effect of financilal development, government spending and EE on EP, the cointegration connection between the variables should be evaluated.

Regression Results

The study estimates three conditional mean (CM) regression models to make a comparison between the results of three different models with the PQR model. **Table 4** shows the results of

TABLE 3 | Results of unit root test.

Variables	CIPS		IPS	
	First difference	Level	First difference	Level
lnEP	−3.58***	−2.70	−7.48***	1.14
lnGF	−2.99***	−1.42	−4.21***	−0.05
lnEE	−3.97***	−2.42	−3.45***	−2.02**
lnEdu	−3.48***	−1.81	−3.17***	−0.41
lnInfs	−3.12**	−2.54	−3.25***	−0.32
lnU	−3.26***	−1.39	−5.33***	−0.07
lnT	−3.97***	−2.42	−3.45***	−2.02**
lnRE	−3.48***	−1.81	−3.17***	−0.41
lnFDI	−3.12**	−2.54	−3.25***	−0.32
lnNR	−3.26***	−1.39	−5.33***	−0.07

1% level of significance.

TABLE 4 | OLS regression results.

Variables	OLS pooled	OLS one-way fixed effect	OLS two-way fixed effect
lnGF	0.4263	0.5162	0.52635
	0.02465	0.03045	0.0203
lnRE	0.6293	0.61625	0.4988
	0.1102	0.13485	0.09425
lnEE	1.09185	1.00775	0.94685
	0.0348	0.04205	0.029
lnNRS	15.2714	13.36755	12.96155
	0.55245	0.6786	0.4698
lnEdu	0.03335	0.0261	0.02755
	0.0232	0.029	0.0203
lnFDI	2.1199	1.9198	1.9256
	0.0696	0.08555	0.05945
lnU	0.4872	0.42195	0.2291
	0.1218	0.14935	0.10295
lnT	0.47995	0.3567	0.37845
	0.07395	0.09135	0.06235
Constant	5.252***	5.830***	5.434***
	−2.051	−1.362	−1.597
R^2		0.904	0.908
Country FE		Yes	Yes
Year FE			Yes

1% level of significance.

the three different models. The impact of GF on EP is statistically significant and negative in all models. The results show that in each panel data model, a 1% change in GF will reduce EP by 2.148, 0.429, and 0.506%, respectively. The study findings are consistent with the prior EP literature (Zameer et al., 2020; Barrella et al., 2021; Gafa and Egbendewe, 2021; Khundi-Mkomba et al., 2021; Desvallées, 2022; Eisfeld and Seebauer, 2022). The results show that natural resources (NRES) also affects EP negatively in Latin America. For every 1% change in NRES, EP reduces by 0.723, 1.113, and 1.101%, respectively. The outcomes are statistically valuable and the results are consistent with (Abbas et al., 2022). Furthermore, RE has a negative significant effect on the EP of the Latin American countries. The results are in line with the research of Awaworyi Churchill and Smyth (2021b), Dong et al. (2021), Zhao et al. (2021), Nguyen and Su (2022), and Sule et al. (2022), who discovered that the impact of GovS on EP is U-shaped in developing countries.

Furthermore, all the control variables have singinficant positive effect on EP. The result showed that infrastructure development (INF) has negative impact on EP of the Latin American countries. In all models, a 1% increase in INF will reduce EP by 0.689, 1.060, and 1.049%, respectively. The findings are statistically viable at the 1% significance level. These findings are consistant with that of Teschner et al. (2020), it is pointed out that INF help to reduce EP in urban peripheries of Romania and Israel. EE shows a significant negative effect on the EP of the Latin American countries. The findings are justified from the study of Apergis et al. (2021), Bukari et al. (2021), and Kahouli and Okushima (2021), who discovered the negative impact of EE on EP in developing economies. The findings are justified from the study of Boemi and Papadopoulos (2019) and Li et al. (2021) who reached similar conclusions. The findins showed that technolog development (T) has negative impact on EP of the Latin American countries. In all models, a 1% increase in technolog development will reduce EP by 0.855, 0.950, and 0.953%, respectively. The findings are justified from the study of Ampofo and Mabefam (2021), Kay et al. (2021), Riva et al. (2021), and Barrella et al. (2022).

Quantile Regression Model

The PQR estimation results on the effect of Green finance, government spendings and EE on EP are presented in **Table 5**. The results are shown for each dependent variable's quantile (10th, 20th, and 90th) percentile distribution. All of the models' results show that numerous factors for each of the three dependent variables are heterogeneous. Moreover, because fixed effect PQR can model the entire conditional distribution, it is a viable option. As a result of variable quantiles, it shows how independent variables affect the dependent variable in a different of ways. Quantile regression under takes the latent heterogeneity of each cross-section and assesses varied coefficients for different quantiles. For policy perspectives, it is also interesting to evaluate the values of the coefficients at the ends of the distribution.

The estimated coefficient (0.294, 0.356, and 0.363%) of GF is positive and statistically significant in the lower quantile (5th, 10th, and 30th), while it is negative and statistically significant in the middle (40th, 50th, and 60th) and upper quantile (70th, 80th, and 90th), at 1% significance level, implying that GF helps to alleviate EP. Irrespective of the size or variable of GF, it demonstrates that GF is a significant and consistent factor in reducing EP. Overall, the findings clarifies that as the level of GF increases by 1%, the level of EP falls by 0.046–0.723%, which is in line with our expectations. In addition, GF reduces energy consumption by assisting businesses in improving EE (Kay et al., 2021) and producing advanced energy-saving products by modernizing production technologies (Zhang et al., 2021) and equipment and increasing investment in R&D (Paramati et al., 2022). Furthermore, energy access is essential for increasing

TABLE 5 | The impact of Green finance, government expenditure, and energy efficiency on energy poverty.

Variables	10th	20th	30th	40th	50th	60th	80th	90th
lnGF	0.294***	0.356***	0.363***	0.369***	0.393***	0.399***	0.407***	0.408***
	(0.017)	(0.021)	(0.014)	(0.016)	(0.019)	(0.021)	(0.022)	(0.017)
lnEE	0.753***	0.695***	0.653***	0.615***	0.570***	0.501***	0.444***	0.461***
	(0.024)	(0.029)	(0.020)	(0.023)	(0.026)	(0.030)	(0.032)	(0.023)
lnNRS	10.532***	9.219***	8.939***	9.200***	9.351***	9.485***	8.001***	5.994***
	(0.381)	(0.468)	(0.324)	(0.369)	(0.421)	(0.476)	(0.495)	(0.374)
lnEdu	0.023***	0.018***	0.019***	0.023***	0.022***	0.007***	0.007***	0.023***
	(0.016)	(0.020)	(0.014)	(0.016)	(0.018)	(0.020)	(0.021)	(0.016)
lnFDI	1.462***	1.324***	1.328***	1.341***	1.331***	1.308***	1.479***	1.285***
	(0.048)	(0.059)	(0.041)	(0.046)	(0.054)	(0.060)	(0.063)	(0.047)
lnU	0.336***	0.291***	0.158***	0.132***	0.179***	0.198***	0.081***	0.198***
	(0.084)	(0.103)	(0.071)	(0.081)	(0.092)	(0.104)	(0.109)	(0.082)
lnT	0.331***	0.246***	0.261***	0.264***	0.248***	0.202***	0.401***	0.274***
	(0.051)	(0.063)	(0.043)	(0.049)	(0.057)	(0.064)	(0.066)	(0.050)
lnGovP	0.434***	0.425***	0.344***	0.437***	0.588***	0.642***	0.405***	0.329***
	(0.076)	(0.093)	(0.065)	(0.074)	(0.084)	(0.095)	(0.099)	(0.075)

5% level of significance.

TABLE 6 | Results of the long-run coefficients (dependent variable: energy poverty).

Variables	CUP_FM	CUP_BC
lnGF	0.294	0.356
	0.017	0.021
lnEE	0.753	0.695
	0.024	0.029
lnNRS	10.532	9.219
	0.381	0.468
lnEdu	0.023	0.018
	0.016	0.020
lnFDI	1.462	1.324
	0.048	0.059
lnU	0.336	0.291
	0.084	0.103
lnT	0.331	0.246
	0.051	0.063
lnGovP	0.434	0.425
	0.076	0.093

quality of life (Radmehr et al., 2021) and is a key necessity for economic development (Adedoyin et al., 2021). When it comes to energy consumption, GF can help to alleviate EP by providing funding for residents to access electricity, technologies, and clean fuels. The development of the financial sector can also provide funding for the transition from energy to green technologies (Khan and Ozturk, 2021). Our research results are consistent with (Zameer et al., 2020). Their research concludes that the alleviation of EP increases by 0.094% for every 1% increase in Green finance.

Renewable Energy

There is a clear negative association between RE and EP in lower and higher quantiles at 1% significance level. Overall, the results imply that 1% increase in RE, the level of EP decreases by 0.046–0.723% and the impact of RE is higher in middle and upper quantiles as compared to lower quantiles. As a result of the findings, it appears that Latin American countries as a whole place a high value on targeted EP alleviation efforts. The financial departments of government's have also delivered a number of heavy punches, such as strongly such promoting infrastructure construction, and rural road, improvement of financial organizations in underprivileged rural areas, reducing the physical distance between financial institutions and farmers. Furthermore, funding for the growth and development of local industry, such as the breeding industry, provides significant focal points and effective carriers for reducing financial poverty. Increased financial transparency and integrity, as well as education in rural areas, have improved poor farmers access to finance, financial literacy, and credit awareness. As a result, the loan default rate has decreased, and poor farmers' use of credit funds has become more efficient. Furthermore, the government should provide Financial targeted poverty alleviation special loan discounts for small loans, and financial institutions involved in development of EP alleviation should be relieved of their concerns. Although the support of government fiscal expenditures, the rural financial system has improved its performance in terms of financial poverty alleviation efficiency.

Energy Efficiency

We find that the estimated coefficient of EE in the lower and upper quantiles is quite highly significant at the 1% level, in the middle quantiles the EE is significant at 5% level. A negative sign indicates that EE reduces EP, this indicates that EE encourages the reduction of energy produced by traditional technologies (Nguyen and Nasir, 2021) and reduce the use of fosil fuels (Chen et al., 2021) and increases access to electricity (Siksnelyte-Butkiene et al., 2021) and electricity consumption per capita (Anser, 2019), thus reducing EP. During the period of austerity and reduction of EP, improving EE is called an economic savior (Agyekum, 2020). EE is of great importance in solving energy

TABLE 7 | Causality test.

Null hypothesis	Wald stattictics	*p*-Value	Decision
lnGF does not cause lnEP	5.876	0.00	lnGF ↔ lnEP (bidirectional causality)
lnEP does not cause lnGF	4.225	0.05	
lnGovS does not cause lnEP	4.694	0.00	lnGovS ↔ lnEP (bidirectional causality)
lnEP does not cause lnGovS	2.687	0.03	
lnEE does not cause lnEP	5.201	0.00	lnEE → lnEP (unidirectional causality)
lnEP does not cause lnEE	2.474	0.49	
lnU does not cause lnEP	9.874	0.00	lnurban → lnEP (unidirectional causality)
lnEP does not cause lnU	2.376	0.74	
lnFDI does not cause lnEP	4.740	0.00	lnFDI ↔ lnEP (bidirectional causality)
lnEP does not cause lnFDI	4.523	0.00	

problems, especially in countries that lack energy autonomy. Our findings are in line with Nguyen and Nasir (2021), they also found similar results that EE significantly reduces EP in poor countries.

The control variable results are also included in the model. First, the impact of urbanization on EP can be seen from the results. The coefficient (0.336, 0.29, 0.158, and 0.132%) of URB at lower quantiles (10th, 20th, 30th, and 40th quantile) is clearly positive and significant. Further the coefecent of urbanization becomes insignificant at the 50th quantile, then turns significant again and becomes negative at the higher quantiles (80th, 90th, 95th quantile), suggesting that increased urbanization results in increased EP in low energy poor countries, In high-energy-poor countries, however, the opposite is true. Second, the findings of FDI in our results are obviously heterogeneous, and the coefficient of FDI is insignificant and negative, which is not enough to support the hypothesis of energy-poor countries. Among them, the coefficient of the upper middle quantile is negative and significant at the 1% level. The insignificant results of the low quantile indicate that most foreign investment is in the non-energy sectors of energy poor countries that may be concerned about EP. Third, the government's ability to implement policies and regulations have significant impact on EP. Fourth, the coefficient of government expenditure is significant and positive at the lower and higher quantiles, indicating that a strict policies and regulations can eradicate EP in the energy poor countries, because government regulation has an impact on everything from the harnessing and extraction of energy to the delivery system. Finally, the coefficient of technological innovation is significant and negative at the higher and lower quantiles, signifying that a higher level of technological innovation can eradicate EP in OECD countries.

Long-Run Panel Cointegration

Since each variable in the models has been logarithmically transformed, **Table 6** presents the estimation outcomes for long-run panel cointegration coefficients, which can be interpreted as elasticity. The study mainly focus on the findings of Green

TABLE 8 | Robustness test.

Variables		5th	10th	20th	30th	40th	50th	60th	80th	90th
lnGF	λ = 0.1	0.297	0.306	0.370	0.378	0.384	0.409	0.415	0.423	0.424
		0.017	0.018	0.022	0.015	0.017	0.020	0.022	0.023	0.018
lnGovS		0.438	0.451	0.442	0.358	0.454	0.612	0.668	0.421	0.342
		0.077	0.079	0.097	0.068	0.077	0.087	0.099	0.103	0.078
lnEE		0.760	0.783	0.723	0.679	0.640	0.593	0.521	0.462	0.479
		0.024	0.025	0.030	0.021	0.024	0.027	0.031	0.033	0.024
lnGF	λ = 0.50	0.317	0.327	0.396	0.404	0.411	0.437	0.444	0.453	0.454
		0.018	0.019	0.023	0.016	0.018	0.021	0.023	0.024	0.019
lnGovS		0.468	0.483	0.473	0.383	0.486	0.654	0.714	0.451	0.366
		0.082	0.085	0.103	0.072	0.082	0.093	0.106	0.110	0.083
lnEE		0.813	0.838	0.773	0.727	0.684	0.634	0.558	0.494	0.513
		0.026	0.027	0.032	0.022	0.026	0.029	0.033	0.036	0.026
lnGF	λ = 1.0	0.374	0.386	0.467	0.477	0.485	0.516	0.524	0.534	0.536
		0.022	0.022	0.028	0.018	0.021	0.025	0.028	0.029	0.022
lnGovS		0.553	0.570	0.558	0.452	0.574	0.772	0.843	0.532	0.432
		0.097	0.100	0.122	0.085	0.097	0.110	0.125	0.130	0.098
lnEE		0.959	0.989	0.913	0.857	0.808	0.748	0.658	0.583	0.605
		0.031	0.032	0.038	0.026	0.030	0.034	0.039	0.042	0.030
lnGF	λ = 1.5	0.431	0.444	0.538	0.548	0.557	0.593	0.603	0.615	0.616
		0.025	0.026	0.032	0.021	0.024	0.029	0.032	0.033	0.026
lnGovS		0.636	0.655	0.642	0.519	0.660	0.888	0.969	0.612	0.497
		0.111	0.115	0.140	0.098	0.112	0.127	0.143	0.149	0.113
lnEE		1.103	1.137	1.049	0.986	0.929	0.861	0.757	0.670	0.696
		0.035	0.036	0.044	0.030	0.035	0.039	0.045	0.048	0.035

*Standard errors in parentheses ***p < 0.01, **p < 0.05, *p < 0.1. *,**, and *** means 10, 5, and 1% significance level.*

finance, EE, and government spending. The estimation results are as follows: at a 1% significance level, the estimators show that Green finance has a enhancing and significant negative effect on EP. It means that as Green finance as a measure of affluence rises, EP decreases. The results of EE confirm that EE and EP have a negative relationship. We believe that EE is a technical indicator. The reduction in energy consumption is a result of improved EE. According to expectations, improvement in EE due to technological innovation has a reducing effect on EP. Furthermore, fiscal spending negatively influence EP.

Causality Test

Finally, the causality test was used to investigate possible bi-directional causality association between Green finances and EP in this study. Prior to undertaking a causality test, stationarity is required. Because our panel is stationary, as evidenced by the panel unit root test results. However, the research examines the relationship between the variables' causality. Since then, various panel data techniques are being used to confirm the variables' relationship. The causality test is now required to determine the direction of the relationship. To determine whether the observed variables are causal, the DH granger causality test is used. The study used the bootstrap method to conduct this test because the results of the slope heterogeneity and CSD tests indicated the presence of heterogeneity and CSD in the panel. The results of the causality test are shown in **Table 7**. The existence of a bidirectional causality relationship between Green finances and EP can be verified. In other words, Green finances have an impact on EP, while changes in EP effect Green finances. The results of the causality tests also show that EE and EP have a one-way relationship, whereas GDP per capita, urbanization, and EP have a two-way relationship.

Robustness Test

In this section, we perform robustness test to ensure the validity of our findings. Various values for λ are considered in the robustness test. The results of the study were tested to see if they were robust to different input values of λ. We conduct test with various values of λ varying from 0.1 to 1.5. To check robustness test, we only show the most important variables interest. **Table 8** summarizes the findings. The results are nearly identical to those of the PQR with = 1. These findings corroborate our previous findings, which are listed in **Table 6**. In short, the sensitivity test confirms that GF, GovS, and EE have a positive and consistent impact on EP in Latin American countries. As a result, our findings are robust when we use different proxies and change the regression approach.

CONCLUSION AND POLICY RECOMMENDATION

Poverty alleviation is a serious practical and social issue that people all around the world are dealing with. Similarly, it must be addressed as part of the process of establishing a prosperous society. Despite numerous attempts to reduce global EP, the problem persists, with the incidence of EP being higher in developing countries. Despite its potential to aid in the fight against EP, the Green finance, and EP nexus has received little attention among the many policy options being considered in the literary space. Thefore the major aim of this research is to find out how Green finance, government spending, and EE affects EP. The PQR approach is used to achieve the objective of the study. This technique considers unobserved individual heterogeneity as well as distributional heterogeneity. In addition, several related control variables are included in the model to avoid an omitted-variable bias. We believe that PQR models can provide a more thorough view of the indicators that influence EP than OLS mean regression. This study examines the annual sample period in the Latin American countries from 2005 to 2018. Overall, the findings showed that Green finance has a positive impact on EP, which is supported by alternative quasi-experimental methods. Other sensitivity checks, such as alternative weighting systems for Green finance and multidimensional EP, as well as alternative EP cut-offs, show that it is robust. Moreover, the government spending and energy efficeicny has a signifincat effect on EP. We conclude that Green finance, government spending, and EE significantly alliviate EP in the 33 Latin American countries.

Finaly, these findings may be useful to policymakers and governments because they can assess how EP has evolved in Latin American countries over the last 16 years, particularly in light of the financial crisis, which countries were the most affected, and which parameters can be considered EP determinants. As a result, plans and initiatives will be implemented more effectively and directly, potentially leading to the successful mitigation and eradication of EP in Latin American countries. These findings will also aid in the successful prevention and the development of resilience of an increase in EP levels as a result of a future economic crisis. EP drivers must be identified in order to successfully reduce negative outcomes through targeted policies, especially in light of the recent COVID-19 pandemic, which had direct and severe socioeconomic impacts on industrial sector, potentially worsening EP conditions.

Policy Recommendation

We put forward some policy recommendations based on the outcomes of this study.

The impact of Green finance in reducing EP has been found to be quite beneficial. As a result, it is recommended that policymakers focus and develop precise plans for delivering financial assistance to those in need. Furthermore, concentrating on the construction and improvement of government funding risk-sharing and guarantees arrangements, as well as utilizing financing platforms of government such as small loans with greater flexibility. For financial poverty alleviation, policymakers must implement local financial support programs on a serious basis, after that, it may concentrate on developing a modern, inclusive rural finance system. The rural revitalization strategy should be implemented as soon as possible. Poverty alleviation is the primary goal of creating a prosperous society in general. As a result only a strong financial support for rural revival policies can encourage the rural sector to experience fresh growth.

Technological innovation is critical for the alleviation of EP; therefore, it is recommended that technological innovation determination to alleviate poverty be strengthened, and to alleviate poverty technological innovation be promoted through market mechanisms. Incentives should be strengthened, and existing innovative talent should be utilized. Make good use of its counter-aid policy, keep looking for new ways to help with technology, and improve scientific research institutions' innovation capabilities. With the right resource endowment, the government can provide new technologies. The agriculture sector and rural poverty are two areas where technological innovation can be focused. Adopting the technological production capacity of natural environment, innovation, social, and economic conditions can all play a key role. The importance of technological advancements is also demonstrated by the fourth industrial revolution; thus, focusing on this point in policy making will benefit people and the economy in the long run.

Energy poverty has a direct impact on the country's ability to meet its long-term sustainable development goals, according to the findings of this study (SDGs). Transitioning from fossil fuels to solar and wind power is a good thing, because it can help the country better withstand EP shocks (but only partially). Countries should not rely solely on green energy policy as a panacea for all of their development challenges, even if this policy shift is beneficial. In addition, countries that are adopting RE should be aware of the potential risks and devise measures to minimize these risks.

Limitations

Long-term unavailability of data was a major limitation faced in conducting this study. Therefore, a country-specific analysis could not be performed. As part of the scope of future research, this study can be replicated to other groups of economies to examine the overall generalizability of the findings.

DATA AVAILABILITY STATEMENT

The original contributions presented in this study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

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Towards sustainable development in China: How do green technology innovation and resource misallocation affect carbon emission performance?

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Green technology innovation is an effective way through which to achieve carbon neutrality and sustainable development. Based on provincial panel data of 30 provinces in China from 2005 to 2018, this work examines the tripartite relationship among green technology innovation, resource misallocation, and carbon emission performance by constructing panel regression models and a dynamic threshold panel model. The research results show that green technology innovation significantly improves carbon emission performance. Further analysis shows that both capital and labour misallocation have a negative impact on carbon emission performance and hinder the contribution of green technology innovation to the improvement of carbon emission performance. The regression results show that there is a threshold effect of green technology innovation on carbon emission performance: as the degree of resource misallocation increases, the positive impact of green technology innovation on carbon emission performance gradually decreases. This study provides an important reference for policy-makers in implementing policies to improve carbon emission performance. Policy-makers should continue to promote the level of green technology innovation and improve the efficiency of labour and capital allocation.

KEYWORDS

green technology innovation, carbon emission performance, China, capital misallocation, labour misallocation

Introduction

Climate change has become the most serious challenge to global sustainable development (Nordhaus, 2019; Heyd, 2021; Zhou et al., 2022). The massive energy consumption brought about by accelerated urbanization and industrialization has led to increased carbon emissions with serious consequences for living systems and the global climate as a whole (Wu et al., 2020; Sufyanullah et al., 2022). The United Nations Framework

Convention on Climate Change (UNFCCC), Kyoto Protocol, and Paris Agreement have established a framework for global climate governance and low-carbon green development, among which the Paris Agreement clarifies the common but differentiated responsibilities of all countries. Statistics from the Statistical Review of World Energy show that China's CO2 emissions in 2020 were 9,899.3 million tons, accounting for 30.7% of the world total. As the largest carbon emitter in the world, China faces enormous challenges in many areas, including climate change, economic transformation, environmental protection, and green development (Liu et al., 2022). China has assumed the responsibility of being a major country in terms of addressing climate change and has pledged to achieve a carbon emission peak by 2030 and reduce carbon emission intensity by 60–65% compared with the 2005 levels. To achieve this goal, China has taken many energy conservation and emission reduction measures, such as optimizing and adjusting the energy structure, improving energy utilization efficiency, promoting the economic and intensive use of natural resources, and launching online trading in the national carbon market (Yang et al., 2021b). There is no doubt that the effective implementation of energy conservation and emission reduction will inevitably lead to carbon peaking and carbon neutrality (Sun et al., 2022; Zeng et al., 2022).

Green technology innovation and rational resource allocation are the key approaches to solving carbon emissions and environmental problems (Razzaq et al., 2021). Green technology is a modern technology system that is in coordination with the ecological environment system, including pollution prevention technology, source emission reduction technology, waste reduction technology, recycling production technology, green products, and purification technology (Zhang and Li, 2022). Moreover, green technology has good positive externalities and can produce good social and environmental benefits. Green technology innovation can improve the utilization efficiency of raw materials and energy, reduce the cost of resource utilization, and alleviate environmental pollution, which are all conducive to the realization of green, low-carbon, and sustainable development (Lv et al., 2021; Chen et al., 2022). Moreover, rational resource allocation can reduce resource waste and improve resource utilization efficiency. However, due to the impact of the planned economy, China is currently facing a serious overcapacity problem. Resource misallocation can be found in different ownership structures, regions, and industries, in turn reducing total factor productivity and increasing carbon emissions and environmental pollution. In addition, China has a vast territory, and its resource endowment varies greatly from place to place. Local protectionism, market segmentation, and local market access systems severely restrict the free flow of resources and hinder the smooth economic cycle (Hao et al., 2020a).

According to neoclassical economic growth theory, economic growth depends on the advancement of technological factors and the increase in the input of labour and capital factors (Solow, 1957). Due to global warming and green development, China has insisted on promoting green and low-carbon transformation and development. Therefore, in such a limited energy environment, carbon emission and energy factors are included in the TFP growth calculation, and the total factor carbon emission performance obtained can accurately estimate the economic development mode (Xu et al., 2021). Referring to the measurement mode of carbon emission performance (Xu et al., 2021), this paper focuses on the impact of green technology innovation and resource misallocation on carbon emission performance.

The literature on green technology innovation, resource misallocation, and carbon emissions is relatively abundant; however, previous studies lacked a systematic incorporation of green technology innovation, resource misallocation, and carbon emission performance into the same analytical framework. Does green technology innovation help improve carbon emission performance? What effect does resource misallocation have on carbon emission performance? Is there a threshold effect on the impact of green technology innovation on carbon emission performance?

To answer the above questions, this work systematically studies green technology innovation, resource misallocation, and carbon emission performance using Chinese provincial panel data from 2005 to 2018. Based on existing research, this paper includes the following three main innovations. First, we put green technology innovation, resource misallocation, and carbon emission performance into the same analytical framework to better study their tripartite relationship. Second, through a moderating effect model, we separately examine the moderating effects of capital and labour misallocation on the impact of green technology innovation on carbon emission performance. Third, a dynamic threshold model is used to test the impact of green technology innovation on carbon emissions through the use of capital misallocation and labour misallocation threshold variables.

The remainder of the article is organized as follows. Section "Literature review" reviews the relevant literature. Section "Methodology and data" presents the model and data. Section "Empirical results and discussion" presents mainly the empirical results and discussion. The conclusions are presented in the final section.

Literature review

Green technology innovation and environmental pollution

With the development of science and technology, green technology has gone through various: terminal treatment technology, waste-free technology, clean technology, renewable energy technology, and pollution prevention technology (Fujii and Managi, 2019). At present, green technology can be regarded as a type of technology that improves the environment, provides ecological protection, and promotes sustainable development in the fields of energy conservation, environmental protection, clean energy, cleaner production, and the circular economy (Wang et al., 2019; Sinha et al., 2020). Climate change and environmental issues have become increasingly prominent, and the relationship between green technology innovation and the environment has received widespread attention. However, there is no consensus on the environmental impact of technological innovation (Ren et al., 2022a), as previous studies have very different views of this impact. Some scholars believe that green technology innovation can reduce carbon emissions and environmental pollution. For example, Álvarez-Herránz et al. (2017) studied 28 OECD countries and found that energy innovation helps reduce greenhouse gas emissions. After researching select OECD economies, Ganda (2019) argued that improving renewable energy technology and spending on R&D could reduce carbon emissions, suggesting that countries should promote the use of green energy and prioritize R&D activities. Moreover, Yuan et al. (2022) argued that green innovation could reduce carbon dioxide emissions and that when institutional quality is higher, green innovation has a stronger reduction effect on carbon dioxide emissions. After constructing a spatial Durbin model and a threshold model, Ren et al. (2022a) suggested that the development of internet technology reduces not only local environmental pollution but also that in adjacent areas.

However, other viewpoints hold that the effects of green technology innovation on carbon emissions and the environment are not significant. Through a study of 71 economies, Du et al. (2019) found that for those with lower income levels, green technology innovation makes no significant contribution to reducing carbon emissions. Wang and Zhu (2020) suggested that the effect of energy technology innovation on carbon dioxide emission reduction be differentiated. Renewable energy technology innovation contributes to carbon dioxide emission reduction, but fossil energy technology innovation does not play a role in reducing carbon emissions. Furthermore, Adebayo and Kirikkaleli (2021) found that technological innovation increased Japan's CO2 emissions in both the short and medium terms.

Research on resource misallocation

In an economy where resources can flow freely enough to achieve Pareto optimality, efficient resource allocation is said to exist, and resource misallocation denotes a deviation from this ideal state (Berthou et al., 2019; Wang et al., 2021). Resource misallocation usually includes capital misallocation, labour misallocation, land misallocation, and other types of misallocation (Hao et al., 2020a). Specifically, capital misallocation occurs mainly because funds, as scarce resources, cannot flow freely to industries and regions that can generate higher economic benefits, which violates the objective laws of economics (Huang et al., 2021). The main reasons for capital misallocation are financial frictions, corporate investor preferences, government subsidies, credit bias among banks, financial repression, and insufficient corporate financial liquidity and financial pledge capacity.

Labour is an important production factor, and the labour market is a market involving two-way choices. Workers choose high-quality enterprises based on their own experience, education, expertise, preferences, and career ideals. Companies usually select excellent employees based on their differentiated characteristics. Therefore, due to information asymmetry, differences in the capabilities of firms and workers can lead to labour misallocation (Kong et al., 2021). Moreover, there is a labour shortage in economically developed areas along the eastern coast of China, while in the inland areas of the western region that have large populations, there is a labour surplus. The optimal allocation of labour resources is from west to east. However, factors such as the household registration system hindering free labour movement eventually lead to labour misallocation.

In summary, capital misallocation and labour misallocation have caused many problems, such as aggravating the imbalance of regional and industrial development, reducing total factor productivity, bringing about excess capacity, economic losses, and environmental pollution, hindering the smooth economic cycle, and restricting economic development (Wang et al., 2020; Hao et al., 2020a).

Research on carbon emissions

As a key factor in climate change, carbon emissions have attracted extensive attention. At present, studies on carbon emissions focus mainly on the measurement method, influencing factors, and efficiency of carbon emissions, as well as the trading of carbon emission rights (Dauda et al., 2021; Wu et al., 2021). Moreover, from the perspective of carbon emission measurement, there are four main methods: the actual measurement method, mass balance method, factor decomposition method, and IPCC inventory method (Krisnawati et al., 2021; Nie et al., 2022). Specifically, the actual measurement method is used mainly in natural ecosystems, with total emissions being calculated according to the flow, speed, concentration, etc., of the emission gas collected through observation. The mass balance method is used mainly in industrial production processes to calculate gas emissions according to the law of the conservation of the input and output of substances. Both the factor decomposition method and IPCC inventory method are used for fossil energy consumption, with the former being used to quantitatively estimate and analyse carbon emissions based on the construction of mathematical models and the latter being based mainly on energy performance consumption. In actual research, most scholars have used the "2006 IPCC Guidelines for National Greenhouse Gas Inventories," published by the IPCC, to measure carbon emissions (Wu et al., 2020; Hao et al., 2021). Moreover, regarding the influencing factors of carbon emissions, previous studies have used mainly three methods—index decomposition analysis (IDA), structural decomposition analysis (SDA), and stochastic impacts by regression on population, affluence, and technology (STIRPAT)—to analyse the influencing factors of carbon emissions. Among them, the decomposition method can determine the actual contribution of each factor to carbon emissions. Additionally, although the STIRPAT model can flexibly incorporate a variety of influencing factors into the model for analysis according to corresponding theory, it can estimate only the elastic coefficient of each influencing factor. In addition, existing studies have attributed the factors affecting carbon emissions mainly to economic development, the energy structure, energy efficiency, population size, the industrial structure, urbanization level, and technological progress.

In general, scholars have carried out a series of studies on green technology innovation, carbon emissions, resource misallocation, and environmental pollution (Hao et al., 2020a; Du et al., 2021; Ren et al., 2021; Chen et al., 2022). However, a more in-depth and systematic analysis of the tripartite relationship among green innovation, resource misallocation, and carbon emission performance is lacking. First, few studies have explored the impact of green technology innovation on carbon emission performance from the resource allocation perspective. Second, we examine whether capital and labour misallocation weaken the impact of green technology innovation on carbon emission performance. In addition, we examine whether there is a threshold effect between the impact of green technology innovation and carbon emission performance. If such an effect exists, then an effective adjustment mechanism needs to be established in the process of developing green technology innovation. Currently, with the acceleration of urbanization, resource misallocation, and environmental pollution are becoming increasingly serious (Hao et al., 2020a; Yang et al., 2021a). Therefore, this article analyses green technology innovation, resource misallocation, and carbon emission performance from the above perspectives.

Methodology and data

Econometric methodology

Basic linear model

This paper focuses on the tripartite relationship among green technology innovation, resource misallocation, and carbon emission performance. Therefore, an econometric model is constructed as shown in Equation (1). Considering that we focus on capital misallocation and labour misallocation, this work constructs the following econometric models, as shown in Equations (2–4):

$$cep_{it} = \beta_0 + \beta_1 lngti_{it} + \beta_2 pgdp_{it} + \beta_3 ce_{it} + \beta_4 open_{it} + \beta_5 gov_{it} + \beta_6 fdi_{it} + \alpha_i + v_t + \varepsilon_{it} \quad (1)$$

$$cep_{it} = \beta_0 + \beta_1 rk_{it} + \beta_2 pgdp_{it} + \beta_3 ce_{it} + \beta_4 open_{it} + \beta_5 gov_{it} + \beta_6 fdi_{it} + \alpha_i + v_t + \varepsilon_{it} \quad (2)$$

$$cep_{it} = \beta_0 + \beta_1 rl_{it} + \beta_2 pgdp_{it} + \beta_3 ce_{it} + \beta_4 open_{it} + \beta_5 gov_{it} + \beta_6 fdi_{it} + \alpha_i + v_t + \varepsilon_{it} \quad (3)$$

$$cep_{it} = \beta_0 + \beta_1 rk_{it} + \beta_2 rl_{it} + \beta_3 pgdp_{it} + \beta_4 ce_{it} + \beta_5 open_{it} + \beta_6 gov_{it} + \beta_7 \ln fdi_{it} + \alpha_i + v_t + \varepsilon_{it} \quad (4)$$

where cep_{it} represents carbon emission performance; gti_{it} denotes green technology innovation; rk_{it} *and* rl_{it} represent capital misallocation and labour misallocation, respectively; *i* and *t* denote province and time, respectively; and ε_{it} is the random disturbance term. The control variables include economic development ($pgdp_{it}$), carbon emissions (ce_{it}), trade openness ($open_{it}$), government intervention (gov_{it}), and foreign direct investment (fdi_{it}).

Dynamic threshold panel model

To analyse the threshold effect between green technology innovation and carbon emission performance under different degrees of capital misallocation and labour misallocation, we refer to the research of Ren et al. (2022b) and use a dynamic threshold model to separately discuss their impact on GTFEE with corruption and market segmentation as threshold variables. The threshold regression model is established as follows:

$$cep_{it} = \beta_0 + \beta_1 lngti_{it}\ I(q_{it} \le c) + \beta_2 lngti_{it}\ I(q_{it} > c) + \sum_{k=1}^{5} \beta_k X_{kit} + \alpha_i + v_t + \varepsilon_{it} \quad (5)$$

where q_{it} represents the threshold variable, which, here, refers to rk_{it} *and* rl_{it} , I(•) represents the indicator function, and c is the specific threshold value.

Data

Carbon emission performance

Referring to Xu et al. (2021), combined with the nonangular and nonradial DDF proposed by Zhou et al. (2012), a DEA calculation model of the environmental total factor productivity growth index based on overall technology is constructed, and then, the carbon emission performance of 30 provinces in China from 2005 to 2018 is measured.

Green technology innovation

Green technology innovation can apply green technology to all stages of production, giving play to the spillover effects of innovation and the environment (Du et al., 2021). This paper uses the total number of green patent grants in each province to measure green technology innovation. Specifically, according to the International Patent Classification Code of Green Patents provided in the Green Patents Inventory issued by the World

Intellectual Property Organization, we screen green patents from the patent database of the State Intellectual Property Office of China based on the date of patent authorization to measure green technology innovation in each province and process them logarithmically (Du et al., 2019).

Figure 1 shows China's green technology level in 2005 and 2018. Overall, Beijing, Guangzhou, Jiangsu and Shanghai are at the forefront of the country's green technology levels. Unlike in Xinjiang, Qinghai, northeast regions, and other regions where the level of green technology innovation has not changed much, in Hebei, Hubei, Liaoning and Yunnan, the level has declined, and in Guangzhou, Jiangsu, Anhui and Fujian, the level has showed an upwards trend.

Resource misallocation

Resource misallocation not only reduces total factor productivity but also affects carbon emission performance. Referring to the theoretical framework of scholars such as Hsieh and Klenow (2009) and Hao et al. (2020a), this work assumes that a factor input has a distorted competitive market and defines the absolute distortion coefficient of the capital factor (*kr*) and labour factor (*lr*) as in Equation (6) as follows:

$$\gamma_K = \frac{1}{1+\tau_{Ki}}, \gamma_L = \frac{1}{1+\tau_{Li}} \qquad (6)$$

where γ_k and γ_L represent the addition of factor inputs. When there are no capital misallocation and labour misallocation, $\tau_{Ki} = 0$, and $\tau_{Li} = 0$, and then, $\gamma_k = 1$, and $\gamma_L = 1$, which means that there is no capital factor and labour factor input addition distortion.

This work further assumes that each province has a C-D production function with constant returns to scale, as shown in Equation (7), in which the real GDP in 2005 is used as the base period to represent the output variable Y_{it}. The capital and labour factor inputs are represented by K_{it} and L_{it}, respectively, where the former is represented by the fixed capital stock of each province, and the latter is represented by the average annual employment of each province. In addition, on this basis, Equation (7) is calculated according to the Solow residual method, the logarithm of both sides of the equation is taken, individual and time effects are controlled in the model, and then, Equation (8) is obtained. Moreover, we add the interaction term of individual dummy variables and explanatory variables to measure the input–output elasticities β_{Ki} of the capital factor and β_{Li} of the labour factor in region i. On this basis, the indicators are substituted into Equation (9) to calculate the relative distortion coefficients $\hat{\gamma}_K$ and $\hat{\gamma}_L$ to approximately replace γ_k and γ_L, respectively. Finally, the index data are substituted into Equation (6) to obtain the capital and labour misallocation indices τ_{Kit} and τ_{Lit}, respectively.

$$Y_{it} = AK_{it}^{\beta_{Ki}} L_{it}^{\beta_{Li}} \qquad (7)$$

$$\ln(Y_{it} / L_{it}) = \ln A + \beta_{Ki} \ln(K_{it} / L_{it}) + \mu_i + \lambda_t + \varepsilon_{it} \qquad (8)$$

$$\hat{\gamma}_K = \left(\frac{K_i}{K}\right) / \left(\frac{s_i \beta_{Ki}}{\beta_K}\right), \hat{\gamma}_L = \left(\frac{L_i}{L}\right) / \left(\frac{s_i \beta_{Li}}{\beta_L}\right) \qquad (9)$$

where K_i represents the capital stock of region *i*, *K* represents the total capital stock of the whole country, and $\frac{K_i}{K}$ represents the ratio of the capital actually used in region *i* to the national capital stock. $s_i \frac{\gamma_i}{\gamma}$ represents the output value of region *i*. Y_i

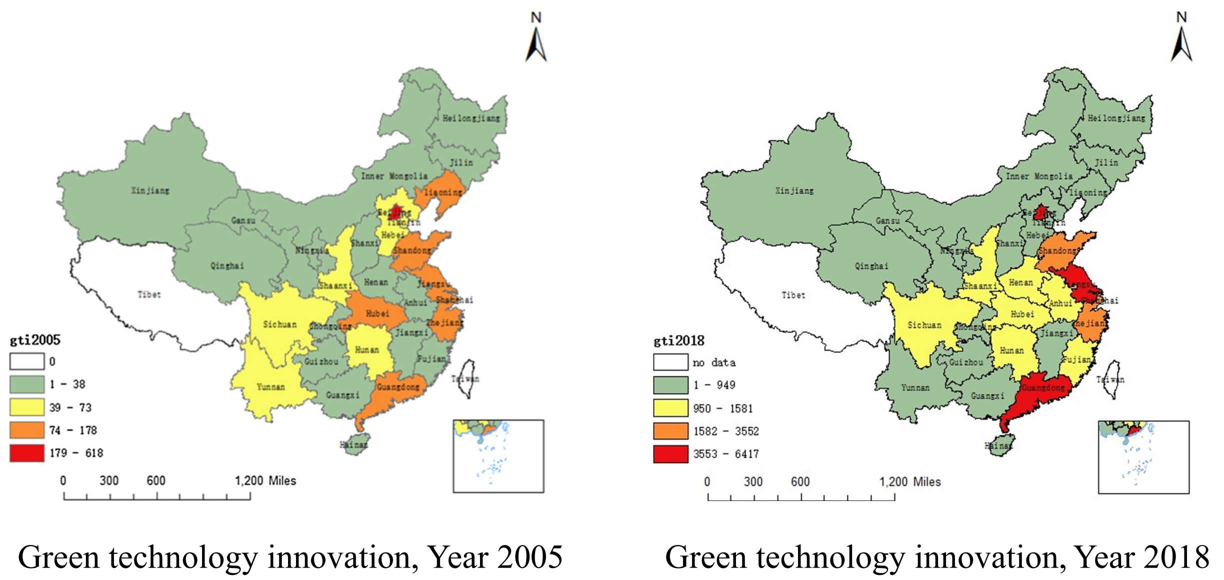

FIGURE 1
China's green technology innovation in the year 2005 and 2018.

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accounts for the share of the total national output value Y. Taking the capital factor as an example, $\beta_K = \sum_i^N s_i \beta_{Ki}$ represents the total input–output elasticity of capital in each region after weighted summation, and $\frac{s_i \beta_{Ki}}{\beta_K}$ measures the theoretical proportion of capital that region i should use under the ideal situation of efficient capital allocation. From the calculation formula of the relative distortion coefficient, it can be seen that if $\hat{\gamma}_K > 1$, then the actual capital used in area ^{i}D exceeds the theoretical value, and the capital is overallocated; otherwise, the actual capital used in area i is insufficient.

Figure 2 shows China's capital misallocation and labour misallocation in 2018. In Xinjiang, Ningxia, Shanghai and Guangdong, capital misallocation is quite serious, followed by Qinghai, Yunnan, Shanxi, Shaanxi, Guizhou, Jiangxi and Anhui, while that in other regions is relatively mild. In 2018, the degree of labour misallocation in Shaanxi, Inner Mongolia, Xinjiang, Heilongjiang, Jilin, and Guangdong is relatively low, while that in Shanxi, Qinghai, Ningxia, Henan, Anhui, Fujian, Sichuan, Guangxi, and Qinghai is more serious. Furthermore, Beijing, Tianjin, Liaoning, Jiangsu, Shanghai, Gansu, Guizhou and Yunnan have the highest degree of labour misallocation.

Control variables

Level of economic development (pgdp)

Rapid economic development requires many resources, thus impacting the environment and carbon emission performance. This study uses *per capita* GDP to represent the economic development level of each province (Wan and Sheng, 2022).

Environmental regulation (eru)

The government's governance of the environment regulates the technological innovation, resource allocation, and carbon emission behaviour of enterprises, thereby affecting their carbon emission performance. This study uses the ratio of completed investment in industrial pollution control to GDP to represent the level of environmental regulation (Hao et al., 2020b).

Level of openness (open)

The rapid development of foreign trade has effectively promoted economic development. However, foreign trade involves a large amount of carbon emissions, which have a serious environmental impact. Therefore, this study uses the proportion of total import and export trade to GDP to measure the level of openness (Ren et al., 2021).

Government intervention (gov)

Government intervention in economic activities through fiscal and monetary policies can affect green technology innovation, resource allocation, and carbon emission performance. Therefore, this study uses the proportion of the general budget expenditure of local finance to GDP to represent the level of government intervention (Su et al., 2021).

Foreign direct investment (fdi)

For regions with high levels of technological innovation and pollution, emission rights and innovation are more inclusive and thus more likely to attract foreign direct investment, further affecting carbon performance; therefore, this study uses the actual utilization of foreign direct investment to measure the level of foreign direct investment (Liu et al., 2018).

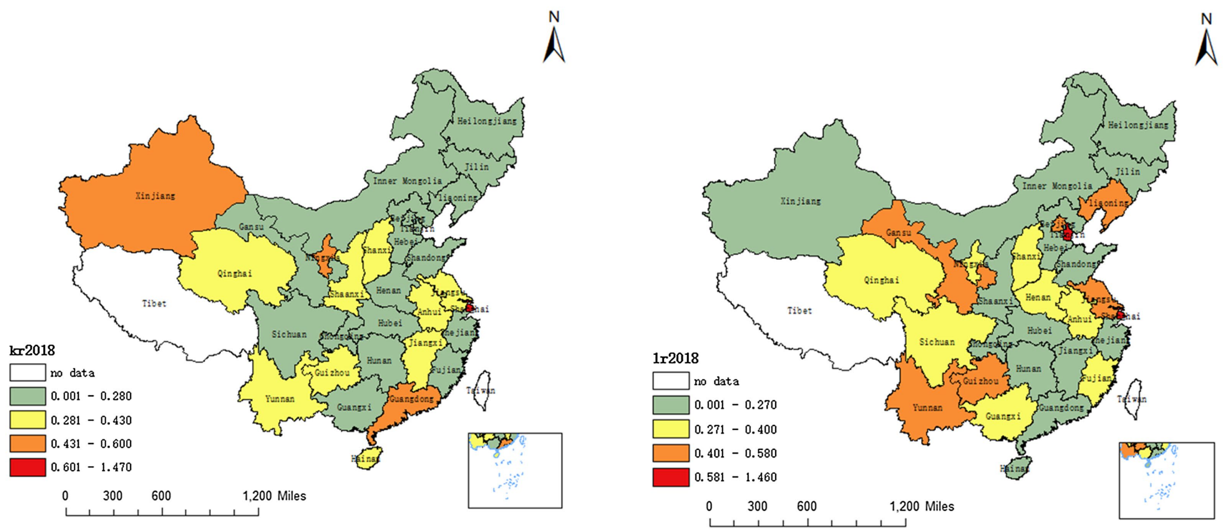

FIGURE 2
China's capital misallocation and labour misallocation in the year 2018.

Data sources

The sample in this paper includes the panel data of 30 provinces in Mainland China (excluding Tibet) from 2005 to 2018. The data sources are the *China Statistical Yearbook, China Environmental Statistical Yearbook, China Energy Statistical Yearbook, China Energy Database, Easy Professional Superior,* and *Wind Database*. This paper addresses the issue of missing data with the imputation method, finally obtaining 420 observations. The descriptive statistics of each variable are shown in Table 1.

Empirical results and discussion

Discussion of the effect of green technology innovation on carbon emission performance

The estimated results of the effect of green technology innovation on carbon emission performance are reported in Table 2. The regression results of OLS, FE, and RE regressions show that the coefficients of green technology innovation are highly positive, indicating that it can effectively improve carbon emission performance. Considering the endogeneity and heteroskedasticity problems in the model, generalized method of moment's estimation is selected to solve this problem. The regression results show that the first-order lag of L.cep is significantly positive, suggesting that carbon emission performance has notable path dependence. Furthermore, no significant change in the sign and significance level of the regression coefficient is found in the SYS-GMM estimation results, and thus, the above conclusion is still valid, mainly because green innovation greatly stimulates green demand, which in turn promotes the development of green industries (Zhu and Tan, 2022). Moreover, the improvement of green technology can reduce resource energy consumption and production costs, leading to the spontaneous flow of production factors to high-productivity sectors, improving industrial production efficiency and resource utilization efficiency, reducing pollution emissions, and enhancing carbon emission performance (Yuan et al., 2022).

Discussion of the effect of resource misallocation on carbon emission performance

As mentioned above, this study analyses mainly capital misallocation and labour misallocation. The samples selected in this paper have the data structure characteristics of "large N and short T." Considering endogeneity and heteroskedasticity

TABLE 2 The regression results of green technology innovation on carbon emission performance.

Variables	OLS	FE	RE	SYS-GMM
L.cep				0.333***
				(6.947)
lngti	0.320***	0.454*	0.311**	0.361**
	(2.880)	(1.911)	(2.386)	(1.986)
pgdp	0.156**	0.425***	0.169**	0.129
	(2.246)	(2.809)	(2.108)	(0.994)
eru	−3.039***	−3.132***	−2.956***	−3.220***
	(−4.170)	(−3.380)	(−3.630)	(−3.945)
open	−0.610*	3.573***	−0.493	−1.167
	(−1.847)	(3.425)	(−1.244)	(−1.144)
gov	−1.356	−11.493***	−2.005	−3.074**
	(−1.236)	(−4.312)	(−1.521)	(−2.248)
fdi	−0.026	0.062	−0.018	−0.041
	(−0.944)	(1.245)	(−0.525)	(−0.808)
_cons	−1.189**	−2.227***	−1.120*	−0.501
	(−2.002)	(−3.073)	(−1.729)	(−0.528)
AR(1)				−3.46
				[0.001]
AR(2)				1.21
				[0.225]
Hansen test				23.58
				[0.958]
R-squared/ Wald test	0.215	0.118	0.213	351.79***
N	420	420	420	420

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.
Figures in () are the *t* values of the coefficients, and figures in [] are the *p* values of the corresponding test statistics. L. is the lag of the variable.

TABLE 1 The statistical description of variables.

Variable	Obs	Mean	*SD*	Min	Max	Unit
cep	420	−0.052	2.201	−10.02	8.730	-
gti	420	5.192	1.664	0.000	8.831	-
kr	420	0.241	0.181	0.000	1.470	-
lr	420	0.417	0.408	0.000	3.050	-
pgdp	420	3.849	2.502	0.522	15.31	10,000 yuan
eru	420	0.002	0.001	0.000	0.011	%
open	420	0.320	0.374	0.018	1.711	%
gov	420	0.235	0.108	0.092	0.758	%
fdi	420	4.104	4.684	0.001	22.57	10 billion yuan

problems, system generalized method of moments estimation is used to analyse the impact of resource misallocation on carbon emission performance. To ensure the validity of the analysis results, we examine the effects of capital misallocation and labour misallocation on carbon emission performance. The regression results in Table 3 show that by gradually increasing the values of the control variables, the regression coefficients of capital misallocation and labour misallocation both become significantly negative, indicating that neither capital misallocation nor labour misallocation is conducive to promoting carbon emission performance. The main reason for this is perhaps that the inverse efficiency flow of factor resources hinders the flow of resources to high-efficiency sectors and enterprises due to resource misallocation (Bian et al., 2019), resulting in reduced resource allocation efficiency, production efficiency, and carbon emission performance, consistent with the findings of Yang et al. (2022). However, the factors that cause resource misallocation include enterprise ownership type, enterprise scale, market segmentation, local protection, and government intervention. Studies have shown that these factors are not conducive to improving resource allocation efficiency, achieving energy conservation and emission reduction, and improving environmental and carbon emission performance (Zhou et al., 2022).

Discussion of the moderating effect of resource misallocation

Capital and labour resources play an important role in green technology breakthroughs and green product marketization. If elemental resources are misallocated, and then green technology innovation faces difficulty in promoting carbon emission performance. To explore the effect of the role of resource misallocation in the impact of green technology innovation on carbon emission performance, this study uses three moderating variables to test the moderating role of resource misallocation in this relationship. These variables are the interaction term of green technology innovation and capital misallocation, that of green technology innovation and labour misallocation, and that of green technology innovation, capital misallocation, and labour misallocation. The regression results in Table 4 show that the coefficients of the three interaction terms are all significantly negative, at −3.363, −4.434, and −0.519. The main reason for this

TABLE 3 The regression results of resource misallocation on carbon emission performance.

Variables	SYS-GMM	SYS-GMM	SYS-GMM	SYS-GMM	SYS-GMM	SYS-GMM
L.cep	0.186***	0.487***	0.403***	0.015**	0.460***	0.363***
	(5.605)	(11.114)	(8.573)	(2.264)	(11.098)	(8.121)
kr	−2.211***	−0.732**	−8.043**			
	(−3.421)	(−2.216)	(−2.394)			
lr				−2.601***	−1.079***	−2.612**
				(−3.986)	(−2.950)	(−2.056)
pgdp		0.146***	0.475***		0.238***	0.326***
		(5.143)	(3.451)		(6.993)	(3.974)
eru		−1.499***	−2.669***		−3.053***	−4.036***
		(−4.684)	(−2.770)		(−6.740)	(−6.950)
open			0.212			1.929
			(0.206)			(0.676)
gov			−0.832			0.951
			(−0.495)			(0.269)
fdi			−0.118**			−0.082
			(−2.537)			(−1.230)
_cons	0.655***	−0.004	1.289	1.037***	0.160	0.044
	(3.925)	(−0.027)	(1.364)	(4.922)	(0.614)	(0.039)
AR(1)	−3.25	−3.61	−3.08	−2.91	−3.49	−3.27
	[0.001]	[0.000]	[0.002]	[0.004]	[0.000]	[0.001]
AR(2)	0.81	1.30	1.31	0.29	1.37	1.35
	[0.418]	[0.194]	[0.189]	[0.772]	[0.169]	[0.176]
Hansen test	29.60	26.60	21.09	28.01	26.16	26.18
	[0.978]	[0.982]	[0.996]	0.793	0.942	0.908
Wald test	684.97***	523.14***	1000.50***	47.56***	2536.38***	387.73***
N	420	420	420	420	420	420

***$p < 0.01$; **$p < 0.05$.
Figures in () are the *t* values of the coefficients, and figures in [] are the *p* values of the corresponding test statistics. L. is the lag of the variable.

is that green technology innovation requires higher efficiency in the creation and use of green knowledge and more capital and talent. If resources are misallocated, then the allocation efficiency of green innovation resources is reduced and carbon emission performance is thus affected. Moreover, the restrictions on labour mobility imposed by the household registration system also limit employment options for green innovative talent. Labour misallocation leads to the inability of green innovation R&D talent to receive reasonable remuneration, thereby weakening the motivation to carry out green innovation activities. Furthermore, if capital misallocation exists, then government intervention in the green credit decisions of financial institutions guides the flow of green credit to low-risk, high-yield constructive projects, making it easier for high-risk, low-return green innovation projects to be faced with financing difficulties. Due to the high demand for green innovation funds and the tightening constraints of green credit funds, enterprises often choose to intensively use tangible elements, such as capital and labour, to carry out production activities, which affects their motivation to carry out green innovation activities. Such a situation is detrimental to the efficient allocation of green innovation resources and adversely affects carbon emission performance.

TABLE 4 The regression results of moderating effect.

Variables	SYS-GMM	SYS-GMM	SYS-GMM
L.cep	0.350***	0.258**	0.444***
	(5.881)	(2.390)	(7.209)
lngtikr	−3.237**		
	(−2.268)		
lngtilr		−4.434**	
		(−2.312)	
lngtikrlr			−0.455***
			(−2.730)
lngti	0.984	1.756**	0.381
	(1.594)	(2.281)	(1.267)
kr	17.771*		4.048
	(1.870)		(1.477)
lr		29.647**	−3.356**
		(2.238)	(−2.005)
pgdp	0.372	0.377	0.209
	(1.130)	(1.528)	(1.469)
eru	−2.063***	−1.362	−1.620**
	(−4.581)	(−0.883)	(−2.573)
open	0.509	−1.206	1.709
	(0.592)	(−0.275)	(1.389)
gov	9.438	1.326	−5.384*
	(1.263)	(0.345)	(−1.767)
fdi	0.007	−0.043	−0.161***
	(0.098)	(−0.346)	(−2.746)
_cons	−8.842**	−12.241**	−0.303
	(−2.439)	(−2.354)	(−0.208)
AR(1)	−2.90	−2.97	−3.42
	[0.004]	[0.003]	[0.001]
AR(2)	1.35	1.16	1.23
	[0.176]	[0.246]	[0.219]
Hansen test	20.26	21.08	18.01
	[0.999]	[0.999]	[0.875]
Wald test	1275.00***	200.32***	1144.95***
N	420	420	420

***$p<0.01$; **$p<0.05$; *$p<0.1$.
Figures in () are the *t* values of the coefficients, and figures in [] are the *p* values of the corresponding test statistics. L. is the lag of the variable.

Discussion of the regression results of the dynamic threshold panel model

The previous empirical results show that resource misallocation has a negative moderating effect on the relationship between the promotion of green technology innovation and carbon emission performance. Is there any heterogeneity in the impact of green technology innovation on carbon emission performance under different resource misallocation levels? To answer this question, a dynamic GMM threshold panel model is adopted to examine the nonlinear effects of green technology innovation on carbon emission performance at different levels of capital misallocation and labour misallocation. The GMM method is used to construct moment estimation conditions, and the threshold model is embedded in the GMM model. The threshold value is determined by the grid search algorithm, thereby obtaining a dynamic GMM panel (Hao et al., 2020a). The test results are shown in Table 5.

Table 5 shows the results of the threshold value and confidence intervals for capital misallocation (k_r) and labour misallocation (l_r). According to the Wald statistics and their *p* values, all the dynamic threshold models with different threshold variables exhibit significant threshold effects at the 1% significance level. Therefore, threshold effects exist. Furthermore, the impact of green technology innovation on carbon emission performance exhibits a nonlinear feature due to resource misallocation.

Table 6 shows the correlation test results of the two-step GMM threshold model regression. According to the results of the correlation test of the residual sequence, there is no second-order autocorrelation for the random error term. The Hansen test results show that the selection of instrumental variables is effective. Therefore, the dynamic threshold regression results in this study are found to be credible.

First, we use capital misallocation as a threshold variable to investigate the impact of green technology innovation on carbon emission performance under different levels of capital misallocation. We find that with the increase in the level of capital misallocation, the regression coefficient of green technology innovation increases, indicating that the higher the degree of capital misallocation is, the greater the negative effect of green technology innovation on carbon emission performance. Then, we use labour misallocation as a threshold variable with which to examine the impact of green technology

TABLE 5 The threshold tests.

Variable	Threshold value	Wald	*p* value	95% CI	
Capital misallocation	0.330	0.805	0.000	0.040	0.550
Labour misallocation	0.080	1.523	0.000	0.050	1.220

TABLE 6 The results of threshold model.

Variable	Kr	lr
	SYS-GMM	SYS-GMM
L.cep	0.287***	0.287***
	(7.46)	(7.39)
pgdp	−0.567***	−0.597***
	(−3.37)	(−4.44)
eru	−5.794***	−5.677***
	(−6.23)	(−6.11)
open	1.411***	1.375***
	(4.29)	(3.81)
gov	−3.436*	−3.883***
	(−1.75)	(−2.94)
fdi	−0.217***	−0.217***
	(−4.97)	(−5.04)
$kr_{it} \leq C$	0.975***	
	(3.64)	
$kr_{it} > C$	0.947***	
	(2.97)	
$lr_{it} \leq C$		1.038***
		(3.36)
$lr_{it} > C$		1.012***
		(4.05)
_cons	−0.658	−0.696
	(−0.68)	(−0.76)
AR (1)	−2.91	−2.95
	[0.004]	[0.003]
AR (2)	0.74	0.71
	[0.461]	[0.475]
Hansen test	20.82	20.40
	[0.470]	[0.496]
Wald test	1168.26***	1622.20***
	[0.000]	[0.000]
N	420	420

***$p < 0.01$; *$p < 0.1$.
Figures in () are the *z* values of the coefficients, and figures in [] are the *p* values of the corresponding test statistics. L. is the lag of the variable.

innovation on carbon emission performance under different levels of labour misallocation. We find that as the degree of labour misallocation increases, the regression coefficient of green technology innovation also increases, indicating that the higher the labour misallocation is, the greater the negative effect of green technology innovation on carbon emission performance. The above empirical results further confirm that both capital misallocation and labour misallocation have inhibitory effects, hindering the effect of the promotion of green technology innovation on carbon emission performance. This finding may be due to the fact that resource misallocation hinders the realization of green technology innovation. On the one hand, green technology innovation requires considerable financial support. However, capital misallocation causes funds to flow into sectors or industries with low productivity, thereby affecting the rational allocation of funds (Kemp-Benedict, 2018). On the other hand, green technology innovation requires a large amount of high-tech talent. However, labour misallocation leads to the loss of high-tech talent, reducing the level of technology innovation, which is not conducive to improving carbon emission performance (Li et al., 2021).

Robustness test

To verify the validity of the above empirical results, this paper uses DIF-GMM model estimation and replaces the explanatory variables to test the robustness of the results. We use the number of green utility model patents granted to represent green technology innovation. The test results are shown in Tables 7, 8. The robustness results show that green technology innovation helps improve carbon emission performance and that capital misallocation and labour misallocation are not conducive to improving carbon emission performance, findings that are consistent with the previous empirical results.

Conclusion and policy implications

To improve carbon emission performance, it is very important to enhance green innovation capabilities. Considering that resources are the basis of green technology innovation, resource misallocation influences the effect of the promotion of green technology innovation on carbon emission performance. Based on provincial panel data of China from 2005 to 2018, this study systematically incorporates green technology innovation, resource misallocation and carbon emission performance into the same analytical framework by using panel regression models and a dynamic threshold panel model. The research conclusions are as follows. (1) Green technology innovation plays a significant role in promoting carbon emission performance. However, capital misallocation and labour misallocation are not conducive to improving carbon emission performance. (2) Resource misallocation plays a negative moderating role in the impact of green technology innovation on the improvement of carbon emission performance. The conclusions remain valid regardless of

TABLE 7 The robustness test (1).

Variables	OLS	FE	RE	SYS-GMM
L.cep				0.340***
				(7.567)
lngti	0.254**	0.690***	0.286**	0.896***
	(2.155)	(2.614)	(2.060)	(3.795)
pgdp	0.191***	0.318**	0.189**	−0.068
	(2.747)	(2.019)	(2.338)	(−0.519)
eru	−3.150***	−2.665***	−2.914***	−3.381***
	(−4.296)	(−2.801)	(−3.495)	(−4.673)
open	−0.553	3.360***	−0.375	−1.480
	(−1.614)	(3.266)	(−0.905)	(−1.473)
gov	−1.431	−12.860***	−2.030	−1.745
	(−1.274)	(−4.697)	(−1.493)	(−1.111)
fdi	−0.025	0.059	−0.018	−0.095*
	(−0.870)	(1.197)	(−0.505)	(−1.909)
_cons	−1.267*	−3.537***	−1.448*	−3.618***
	(−1.671)	(−3.635)	(−1.744)	(−2.724)
AR(1)				−3.36
				[0.001]
AR(2)				1.32
				[0.187]
Hansen test				22.44
				[0.972]
R-squared/ Wald test	0.208	0.117	0.205	635.15***
N	420	420	420	420

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.
Figures in () are the *t* values of the coefficients, and figures in [] are the *p* values of the corresponding test statistics. L. is the lag of the variable.

TABLE 8 The robustness test (2).

Variables	DIF-GMM	DIF-GMM	DIF-GMM
L.cep	0.115***	0.456***	0.281**
	(4.484)	(4.837)	(2.550)
lngti	3.558***		
	(8.494)		
kr		−9.205**	
		(−2.227)	
lr			−7.427**
			(−1.963)
pgdp	−0.617**	0.503***	0.943***
	(−2.239)	(4.544)	(7.711)
eru	−5.567***	−4.225***	−4.817***
	(−8.369)	(−8.744)	(−5.879)
open	−2.479	1.741	7.626***
	(−1.030)	(0.771)	(3.644)
gov	−59.937***	2.108	−11.770***
	(−10.397)	(0.440)	(−5.868)
fdi	0.138***	0.069***	0.149***
	(5.814)	(4.534)	(4.602)
AR(1)	−3.32	−3.07	−2.99
	[0.001]	[0.002]	[0.003]
AR(2)	0.19	1.45	1.15
	[0.846]	[0.148]	[0.251]
Hansen test	29.04	23.23	20.91
	[0.852]	[0.332]	[0.464]
N	420	420	420

***$p < 0.01$; **$p < 0.05$.
Figures in () are the *t* values of the coefficients, and figures in [] are the *p* values of the corresponding test statistics. L. is the lag of the variable.

whether capital and labour misallocation are considered individually or together. (3) Under the effect of resource misallocation, green technology innovation has a nonlinear promotion effect on carbon emission performance. Based on the above conclusions, this study puts forward the policy recommendations presented below.

First, the government should continue to strengthen green technology innovation and improve the innovation guarantee system. Moreover, the government should actively lead the green development of emerging industries, advocate the use of green and low-carbon energy in various departments, and accelerate the development of green products. Energy-saving and environmental protection industries and cleaner production industries should be developed, and traditional manufacturing industries should be encouraged to accelerate their green transformation and upgrading.

Second, the market-oriented reform of factors should be deepened, and the optimal allocation of factor resources should be realized. The government should relax its excessive regulation of resources, reduce excessive intervention in the factor market, and release more market vitality. In addition, the rational allocation of factor resources in different departments and regions should be properly guided. Furthermore, it is necessary to improve the green industry financial system, expand multiple financing channels, adjust the profit and loss of funds through the financial system, guide the flow of funds through the price of funds, and improve capital allocation efficiency.

Third, it is very meaningful to solve labour misallocation by strengthening human capital investment; actively cultivating professional and high-tech talent; improving household registration, land systems and social security systems; removing barriers to labour mobility across departments; and reducing labour mobility costs.

Finally, the government should strengthen its antimonopoly policies, investigate and punish acts of unfair competition in accordance with the law, eliminate local protection and market segmentation, accelerate the establishment of a unified national market system and rules, improve resource allocation efficiency, and promote high-quality economic development.

Although this study analyses the tripartite relationship among green technology innovation, resource misallocation, and carbon emission performance, some limitations exist. Future research can be further expanded in the following aspects. First, based on data availability, more detailed city-level data can be used for analysis. Second, the impact of land misallocation and data misallocation on environmental and carbon performance can be further analysed. Third, green technology innovation, resource misallocation, and environmental indicators can be measured through the use of other methods.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found at: https://data.stats.gov.cn/.

Author contributions

MD: writing—original draft, software, methodology, and project administration. QZ: conceptualization, funding acquisition, supervision, and writing—review and editing. YZ: conceptualization, writing—review and editing, supervision, and validation. FL: data curation, formal analysis, writing—original draft, and visualization. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Toward Sustainable Development: Unleashing the Mechanism Among International Technology Spillover, Institutional Quality, and Green Innovation Capability

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Under the background of sustainable development, China's economic growth engine becomes innovation-driven, and it is an important way for China to rapidly improve its green innovation capability by opening up to the outside world and utilizing the spillover effect of international technology. In this article, the system quality evaluation system is reconstructed by the method of fully arranged polygonal graphical indicators, and the provincial system quality in China is measured and added into the model as a regulating variable. The dynamic panel method and the dynamic threshold panel method are used to test the direct effects of foreign direct investment (FDI) and foreign trade on green innovation capability, the interaction effect of institutional quality, and the threshold effect. Empirical results show that the three technology spillovers have significantly promoted China's green innovation capability. System quality will affect the determining coefficient of international technology spillovers on China's green innovation capability. The positive promoting effects of FDI and foreign trade on China's green innovation capability, all increase with the improvement of China's system quality. Therefore, when utilizing FDI and foreign trade to promote green innovation in each region, each region should consider creating a good institutional environment for the emergence of international technological effects.

Keywords: international technology spillover, institutional quality, green innovation ability, interaction effect, dynamic threshold model

INTRODUCTION

After China's economic development has entered a new normal, it is necessary to promote sustainable economic development (Ahmad et al., 2021; Yang et al., 2021; Fang et al., 2022) with green innovation (Wu et al., 2019; Zhu et al., 2019; Irfan et al., 2020). The report of the 19th National Congress of the Communist Party of China also emphasized many times that "innovation is the first driving force for development," and technological innovation and scientific and technological progress play an important role in driving national economic development (Hao et al., 2021b). Despite the rapid development of China's high-tech industry in recent years, the large investment in research and development (R&D) funds has not completely solved the problems of low efficiency of scientific and technological innovation and weak original innovation ability (Jinru et al., 2021; Irfan and Ahmad, 2022; Abbasi et al., 2022). The long-term existence of this phenomenon will definitely restrict the effective implementation of China's green innovation-driven development strategy (Tang et al., 2021; Wu et al., 2021; Yan et al., 2021). China, as a developing country with a relatively backward technology level, started to implement the independent innovation strategy late (Rauf et al., 2021; Shao et al., 2021; Yumei et al., 2022), but it is still at the low end of the vertical division system of the global value chain (Elavarasan et al., 2021a,b; Tanveer et al., 2021). Nowadays, with the deepening of economic globalization, to make China an innovative country in 2035, it is an important way for China to rapidly improve its independent innovation capability to realize the spillover effect of international technology through the opening to the outside world (Hao et al., 2021a). Besides, whether international technology spillover can play its role smoothly and effectively, the key lies in the influence of the exogenous institutional environment, that is, institutional quality (Gokmenoglu et al., 2015; Hao et al., 2021b). Especially under the condition of an open economy, with the increase in production and transaction links that multinational corporations need to coordinate, if the transaction cost is too high and the transaction risk is difficult to control, it will inevitably hinder the emergence of an international technology spillover effect (Hao et al., 2020). Therefore, how to build a regional institutional quality environment with coordinated development of politics, economy, and law, and make the international technology spillover play the most effective role in improving the green innovation capability, has become an important issue in the development of China's regional innovation capability.

At present, the research on how international technology spillovers affect green innovation capability has not reached a unanimous conclusion, and the absorption effect of international technology spillovers varies greatly in different countries and regions. Some scholars have pointed out that the reverse technology spillover of foreign trade or outward foreign direct investment (OFDI) can significantly enhance the regional innovation capability (Grossman and Helpman, 1993; Coe and Helpman, 1995; Lichtenberg and De La Potterie, 1998; Ho et al., 2013; Kim et al., 2016); while some scholars stressed that FDI or OFDI did not play a substantial role in promoting regional innovation capability (Bitzer and Kerekes, 2008). In addition, some scholars believe that the relationship between international technology spillover and the promotion of green innovation ability of the host country is not simply linear, which requires not only considering the type of foreign investment, it is also necessary to consider the host country's human capital reserve, intellectual property protection, industrial structure, opening level, and other factors (Djankov and Hoekman, 2000; Uotila et al., 2005). Nelson, an American scholar, pointed out in the article "American System Supporting Progress" that reasonable institutional arrangements mainly consist of the market mechanism, intellectual property protection policy, and government role, and deeply analyzed that the innovation ability of the United States benefits from a high-quality social system. In fact, as the basic rule of social and economic operation, it has a profound impact on social development. Poor system quality will increase the tax burden of economic activities, increase transaction costs, and reduce operational efficiency. Problems, such as the administrative monopoly of local governments will also breed rent-seeking and corruption. Good system quality can not only reduce unnecessary obstacles, reduce transaction costs, and the breeding of corrupt rent-seeking activities, it can also reduce the uncertainty in the process of innovation and research, and promote the research, development, innovation, and application of advanced technologies (Shleifer, 1998; Huang and Xu, 1999; Falvey et al., 2006; Tebaldi and Elmslie, 2013). If an institutional system is established in the production activities of enterprises, which can not only effectively motivate people to engage in productive activities but also ensure that all parties involved can fairly realize their rights and obligations, it will not only help to improve the innovation ability but also promote the growth of economic performance of enterprises. Therefore, improving the system quality and creating conditions for the introduction and internalization of international advanced technology are the key to promoting the domestic green innovation capability by using international technology spillover.

Throughout the existing research, it is found that: (1) in the related research on the impact of international technology spillover on green innovation capability, there is a lack of systematic analysis from the perspective of institutional quality, and the selection of indicators is too single to fully reflect the connotation of institutional quality; (2) FDI, OFDI, or a single index of foreign trade are mostly used to measure the international technology spillover index, and few scholars put the three into the same framework for comprehensive consideration; and (3) most of them are limited to static analysis, and its potential endogenous problems will lead to estimation errors. Different from previous studies, this article combines the provincial panel data from 2010 to 2019 and adopts the method of fully arranged polygon graphic indicators to establish the regional system quality evaluation system (Ren et al., 2022). Using direct effect, interactive effect, and threshold effect, this article examines the relationship among international technology spillover, institutional quality, and green innovation capability, and systematically analyzes the influence mechanism of international technology spillover on green innovation capability. To provide theoretical and policy references for China to effectively utilize the spillover effect of international technology to enhance its green innovation capability and realize the transformation of its growth engine to an innovation drive as soon as possible.

THE MEASUREMENT AND ANALYSIS OF SYSTEM QUALITY

Construction of a System Quality Index System

The institution quality is a rather broad concept. As pointed out by North (1989), institution quality should cover all aspects, such as law, property rights, government efficiency, and execution. Since 1978, the internal reform and opening-up to the outside world have undoubtedly been the periods when the quality of China's system has changed most drastically. Under the dual background of internal system transformation and external economic impact, we need to use scientific evaluation methods to measure the system quality of provinces and regions in China. For the measurement of domestic institutional quality in China, its quantification is often subjective and difficult to measure. Therefore, following the research of Ren et al. (2021), this article takes the connotation of system quality as the guiding principle. Based on previous studies, the comprehensive evaluation system of system quality, including political, economical, and legal environment, is reconstructed (as shown in **Table 1**).

Calculation Method

For the evaluation of comprehensive indicators, the previous studies mostly established the evaluation index system and used the analytic hierarchy process (AHP), multivariate statistical analysis, the Delphi method, and the entropy method to establish the evaluation function. However, these evaluation methods lack the dynamic consideration of "time dimension," and even have serious random and speculative defects. Given this, in this article, the fully arranged polygon graphic indicator method is used, which has both static indicators and dynamic trends. It not only reflects the principle of system integration but also avoids the problem of overlapping information among multi-indicator variables and realizes a comprehensive review of the development of institutional quality in various provinces and cities in China from a dynamic point of view. The basic principle of the evaluation method is as follows: set n indicators, construct with the maximum value of these indexes as the radius $(n–1)!/2$ irregular central n-triangles, the vertices of which are the full arrangement of n indicators end to end. The composite index is the ratio of the average of all irregular polygon areas to the central polygon area. The specific calculation process is as follows:

(1) Building a standardized function:

$$F(x) = \frac{a}{bxc} \tag{1}$$

In which, a, b, and c, respectively, represent the parameters of the hyperbolic function.

(2) The hyperbolic normalization function $F(x)$ satisfies the following conditions: $F(U) = 1$, $F(T) = 0$, $F(L) = –1$, where u is the upper limit of index X, l is the lower limit of index X, t is the critical value of index X, and the critical value can be expressed by the average value of index X. Available from the above conditions:

$$F(x) = \frac{(U-l)(x-T)}{(U+L-2T)\,x+UT+LT-2UT} \tag{2}$$

It can be seen from formula (2) that the standardization function $F(x)$ maps the index value located in [L, U] to $[-1, 1]$, and the standardization process will cause the index value to show a fast-slow-fast nonlinear growth trend.

(3) For the ith index, the standardized formula is expressed as follows:

$$S_i(x) = \frac{(U_i-I_i)(x_i-T_i)}{(U_i+L_i-2T_i)\,x+U_iT_i+L_iT_i-2UT} \tag{3}$$

The vertex of the n-polygon is composed of $S_i = 1$, and the center point consists of $S_i = –1$, $S_i = 0$ constitutes the critical value of the polygon index. If above the critical value, each index value is positive, and below the index value, each index value is negative.

(4) The comprehensive indexes of fully arranged polygons are as follows:

$$S(x) = \frac{\sum_{i\neq j}^{i,j}(S_i+1)(S_j+1)}{2n(n-1)} \tag{4}$$

Among them, S is a comprehensive index and S_i is a single indicator.

Result Analysis

According to the results in **Table 2**, the average annual score of China's institutional quality from 2010 to 2019 is 0.222.

TABLE 1 | Construction of a system quality index system.

Primary index	Secondary index	Three-level index	Four-level index	Index attribute
System quality	Legal system environment	Judicial protection level	Proportion of regional lawyers (X_1)	Ascending type
		Administrative protection level	The settlement rate of patent infringement cases (X_2)	Ascending type
			Case closing rate of counterfeiting others' patents (X_3)	Ascending type
		Level of economic development	Per capita GDP (X_4)	Ascending type
		Educational development level	Proportion of junior college or above (X_5)	Ascending type
			Proportion of high school education (X_6)	Ascending type
			Proportion of junior high school education (X_7)	Ascending type
			Proportion of primary schools (X_8)	Ascending type
	Political environment	Regional corruption	The proportion of corrupt people involved (X_9)	Constraint type
	Economic institutional environment	Marketization process	The relationship between government and market (X_{10})	Ascending type
			The development of non-state-owned economy (X_{11})	Ascending type
			Market development degree (X_{12})	Ascending type
			Factor market development degree (X_{13})	Ascending type
			The development of market intermediary organizations (X_{14})	Ascending type

TABLE 2 | System quality measurement in some years in China from 2010 to 2019.

Province	2010		2013		2016		2019		Annual mean	
	Score	Ranking	Score	Ranking	Score	Ranking	Score	Ranking	Comprehensive score	Ranking
Beijing	0.279	3	0.332	3	0.421	2	0.463	4	0.383	3
Tianjin	0.281	2	0.381	1	0.434	1	0.427	10	0.395	1
Hebei	0.148	10	0.082	27	0.236	16	0.306	18	0.178	18
Shanghai	0.318	1	0.281	5	0.335	6	0.434	9	0.348	5
Jiangsu	0.177	8	0.235	7	0.281	10	0.434	8	0.285	9
Zhejiang	0.276	4	0.374	2	0.405	3	0.580	1	0.393	2
Fujian	0.200	7	0.262	6	0.332	7	0.449	7	0.312	6
Shandong	0.213	5	0.232	8	0.302	8	0.424	11	0.286	8
Guangdong	0.168	9	0.195	10	0.263	14	0.454	6	0.269	10
Hainan	0.076	24	0.134	19	0.192	19	0.247	24	0.158	20
Shanxi	0.121	15	0.178	13	0.232	17	0.333	16	0.211	16
Anhui (Province)	0.080	22	0.107	22	0.179	23	0.277	19	0.156	22
Jiangxi	0.076	23	0.102	24	0.162	25	0.270	21	0.150	24
Henan	0.133	13	0.193	11	0.274	12	0.363	14	0.232	13
Hubei	0.104	17	0.154	17	0.228	18	0.381	13	0.211	17
Hunan	0.106	16	0.146	18	0.182	22	0.219	26	0.158	19
Liaoning	0.203	6	0.296	4	0.358	4	0.540	2	0.361	4
Jilin	0.139	12	0.232	9	0.351	5	0.489	3	0.301	7
Amur	0.142	11	0.184	12	0.245	15	0.361	15	0.222	15
Inner Mongolia	0.097	19	0.168	15	0.264	13	0.460	5	0.242	11
Guangxi	0.071	25	0.091	25	0.144	26	0.219	27	0.130	26
Chongqing	0.124	14	0.173	14	0.275	11	0.325	17	0.228	14
Sichuan	0.090	20	0.102	23	0.167	24	0.261	23	0.154	23
Guizhou	0.029	28	0.059	28	0.100	29	0.164	29	0.086	29
Yunnan	0.016	30	0.088	26	0.186	20	0.261	22	0.126	27
Shaanxi	0.069	26	0.131	20	0.184	21	0.271	20	0.157	21
Gansu	0.033	27	0.056	29	0.118	28	0.199	28	0.099	28
Qinghai	0.028	29	0.050	30	0.094	30	0.152	30	0.076	30
Ningxia	0.088	21	0.165	16	0.282	9	0.385	12	0.232	12
Xinjiang	0.099	18	0.107	21	0.141	27	0.240	25	0.134	25
Eastern China	0.214	1	0.251	1	0.320	1	0.422	2	0.301	1
Middle China	0.104	4	0.147	4	0.209	4	0.307	4	0.186	4
Western China	0.068	5	0.108	5	0.178	5	0.267	5	0.151	5
Northeast China	0.161	2	0.237	2	0.318	2	0.463	1	0.295	2
National	0.133	3	0.176	3	0.246	3	0.346	3	0.222	3

Except for the eastern and northeastern regions, the average annual institutional quality is higher than the national average, and all other regions are lower than the national average. The development ladder pattern of the eastern, northeastern, central, and western regions is obvious, and the ranking of regional institutional quality score is unchanged. The score of the new urbanization level in each province shows that except Hebei and Hainan, the average annual system quality scores in the eastern region are higher than the national average, while the average annual system quality scores in all provinces in the northeast region are not lower than the national average[1]. Only Henan in the central region is higher than the national average, while Inner Mongolia, Chongqing, and Ningxia in the western region are higher than the national average. Among them, the top 10 provinces with annual average system quality scores, 8 provinces (Beijing, Tianjin, Shanghai, Zhejiang, Jiangsu, Guangdong, Shandong, and Fujian) are from the eastern region, and 2 provinces (Liaoning and Jilin) are from the northeast region. Among the last ten provinces in terms of annual institutional quality, two provinces (Anhui and Jiangxi) are from the central region. Eight (Guangxi, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, and Xinjiang) are from the western region, and the calculation results basically accord with the current situation of China's regional, political, and economic development. **Table 2** shows the score and ranking of China's regional institutional quality measurement. Due to space constraints, this article only lists the measurement results of some years.

[1]For the convenience of analysis, the term "province" is utilized to represent all provincial administrative units in China, such as provinces, municipalities, and minority autonomous regions.

MODEL AND DATA

Model Building

According to the research of Hao et al. (2021a), it is assumed that international technology spillover will affect the green innovation capability of the host country through FDI, OFDI, and foreign trade. Furthermore, the factors influencing the promotion of green innovation capability, such a human capital, R&D personnel investment, R&D capital investment, and industrial structure, are brought into the model. In addition, in this period, the regional innovation capability will be affected by the early stage, so the lag of innovation capability by one stage is added into the model as an explanatory variable, and the system generalized distance estimation (SYS-GMM) and differential generalized moment estimation (DIF-GMM) are used for estimation. Since the difference generalized moment estimation (DIFF-GMM) first removes the fixed effect of the model by difference, then, the lag period of explanatory variables is used as instrumental variables to construct difference equations, which can reduce the endogenous problems among variables, and the difficulty of searching instrumental variables (Irfan and Ahmad, 2021). The system GMM estimates the difference equation and the level equation as one equation, which can not only improve the efficiency of estimation but also estimate the coefficients of the variables that do not change with time in the model. So that the estimation result is more accurate. Therefore, in this article, the system GMM estimation results shall prevail in the concrete analysis, and the DIF-GMM estimation results are only for comparison without specific explanation. The benchmark model is set as follows:

$$lncreate_{it} = \beta_0 + \beta_1 lncreate_{it-1} + \beta_2 lnfdi_{it} + \gamma lncontrol_{it} + \alpha_i + \varepsilon_{it} \quad (5)$$

$$lncreate_{it} = \beta_0 + \beta_1 lncreate_{it-1} + \beta_2 lnofdi_{it} + \gamma lncontrol_{it} + \alpha_i + \varepsilon_{it} \quad (6)$$

$$lncreate_{it} = \beta_0 + \beta_1 lncreate_{it-1} + \beta_2 lntrade_{it} + \gamma lncontrol_{it} + \alpha_i + \varepsilon_{it} \quad (7)$$

To test the interactive effect (moderating effect) of institutional quality, this article introduces the interactive terms of institutional quality (inst), FDI, and foreign trade, respectively, and transforms the above equation into:

$$lngml_{it} = \beta_0 + \beta_1 lngml_{it-1} + \beta_2 lnfdi_{it} + \beta_3 (inst_{it} \times lnfdi_{it}) + \gamma lncontrol_{it} + \alpha_i + \varepsilon_{it} \quad (8)$$

$$lngml_{it} = \beta_0 + \beta_1 lngml_{it-1} + \beta_2 lnofdi_{it} + \beta_3 (inst_{it} \times lnofdi_{it}) + \gamma lncontrol_{it} + \alpha_i + \varepsilon_{it} \quad (9)$$

$$lngml_{it} = \beta_0 + \beta_1 lngml_{it-1} + \beta_2 lntrade_{it} + \beta_3 (inst_{it} \times lntrade_{it}) + \gamma lncontrol_{it} + \alpha_i + \varepsilon_{it} \quad (10)$$

The interaction term is to preliminarily test the regulation effect of institutional quality by the exogenous grouping method. To avoid artificial division of growth intervals and estimation errors caused by endogenous problems in previous static threshold models, this article uses Wu et al. (2020) as a reference to study the dynamic threshold panel model and sets the following dynamic threshold panel model:

$$lncreate_{it} = \beta_0 + \beta_1 lncreate_{it-1} + \beta_2 lnfdi_{it} \cdot \mathrm{I}(inst_{it} \le c) + \beta_3 lnfdi_{it} \cdot \mathrm{I}\ inst_{it} > c + \gamma lncontrol_{it} + \alpha_i + \varepsilon_{it} \quad (11)$$

$$lncreate_{it} = \beta_0 + \beta_1 lncreate_{it-1} + \beta_2 lnofdi_{it} \cdot \mathrm{I}(inst_{it} \le c) + \beta_3 lnofdi_{it} \cdot \mathrm{I}\ inst_{it} > c + \gamma lncontrol_{it} + \alpha_i + \varepsilon_{it} \quad (12)$$

$$lncreate_{it} = \beta_0 + \beta_1 lncreate_{it-1} + \beta_2 lntrade_{it} \cdot \mathrm{I}(inst_{it} \le c) + \beta_3 lntrade_{it} \cdot \mathrm{I}\ inst_{it} > c\ \gamma lncontrol_{it} + \alpha_i + \varepsilon_{it} \quad (13)$$

Among them, subscript I represents the province (i = 1,2,3...30), t represents the time, $create_{it}$ represents the green innovation ability, $create_{it-1}$ a lagging term representing the green innovation ability, fdi_{it} indicates FDI; $ofdi_{it}$ indicates OFDI; $trade_{it}$ represents foreign trade; $control_{it}$ a series of control variables that affect the promotion of regional innovation capability, including the industrial structure adjustment index (ind_{it}), R&D personnel investment (rdp_{it}), R&D investment (rd_{it}), human capital level (hum_{it}); and $inst_{it}$ indicates the system quality, which is also a threshold variable; I(·) indicates the index function, and c is the specific threshold value;$\alpha_i$represents the individual fixation effect, in which $\alpha_i = \mu_{it} + \upsilon_{it}, \mu_{it}$ represents the regional fixed effect, υ_{it} is the time fixed effect; and ε_{it} represents a random perturbation term.

Explanation and Description of Variables

In this article, the number of green patent applications in different provinces is taken as the proxy variable of green innovation capability, and the stock of green innovation capability is calculated by the perpetual inventory method with reference to previous studies. Actual FDI, net non-financial FDI, and total import and export volume of China's provinces over the years are used to represent FDI and foreign trade, respectively. The system quality shall be subject to the calculation results in Part II. With regard to control variables, the weighted average of the years of education of the population aged 6 years and above in each region is used to measure the human capital of each province, and the ratio of regional R&D investment to regional GDP is used to express the intensity of R&D investment, and the full-time equivalent of R&D personnel is used as the proxy variable of R&D personnel investment. The industrial structure adjustment index is expressed by the proportion of the annual output value of the tertiary industry and the annual output value of the secondary industry. Statistical information about each variable is shown in **Table 3**.

RESULTS AND ANALYSIS

As mentioned earlier, this article focuses on the relationship between the three international technology spillovers of FDI, foreign trade, and China's green innovation capability, and through what channels it influences China's green innovation

TABLE 3 | Variable description and statistical description.

Variable name	Symbol	Unit	Calculation method
Green innovation ability	*gcreate*	piece	perpetual inventory system Calculated stock
Foreign direct investment (FDI)	*fdi*	Billion dollars	Taking 2006 as the base period Use directly after conversion.
FDI	*ofdi*	Billion dollars	Taking 2006 as the base period Use directly after conversion.
Foreign trade	*trade*	Billion dollars	Taking 2006 as the base period Use directly after conversion.
System quality	*inst*	–	Fully arranged polygon graph Indicator evaluation method
R&D personnel investment	*rdp*	ten thousand people	Use directly
R&D investment	*rd*	%	Use directly
Manpower capital	*hum*	year	Weighted mean number of years of education for population aged 6 and above
Industrial structure adjustment index	*ind*	%	Annual output value of tertiary industry/annual output value of secondary industry

TABLE 4 | Direct effect estimation results.

Variable	Model 1		Model 2		Model 3	
	SYS-GMM	DIF-GMM	SYS-GMM	DIF-GMM	SYS-GMM	DIF-GMM
lngcreate$_{it-1}$	0.708***	0.320***	0.559***	0.681***	0.883***	0.767***
	(76.23)	(2.63)	(11.21)	(34.61)	(69.96)	(11.18)
lnrdp	0.366***	2.544***	0.686***	0.675***	0.234***	0.764***
	(12.36)	(7.93)	(8.31)	(28.82)	(5.72)	(4.46)
lnrd	9.761***	−14.131*	40.055	−0.445***	21.749***	4.431
	(2.91)	(−1.84)	(1.45)	(−2.70)	(4.20)	(1.56)
lnhum	0.093	−4.526***	−0.635	−2.171***	−0.556***	−1.581**
	(0.53)	(−3.41)	(−1.22)	(−6.56)	(−4.42)	(−2.41)
lnind	−9.529***	15.923*	−39.937	−0.445***	−21.726***	−6.098*
	(−2.86)	(1.95)	(−1.44)	(−2.70)	(−4.20)	(−1.89)
lnfdi	0.212***	0.383***				
	(15.89)	(2.63)				
lnofdi			0.157***	0.121***		
			(7.28)	(9.25)		
lntrade					0.039***	0.001
					(6.18)	(0.02)
_cons	0.934***		3.609***		2.048***	
	(2.62)		(3.72)		(8.85)	
AR(2)	1.54	1.14	−0.32	1.25	1.21	−1.36
	[0.123]	[0.255]	[0.752]	[0.211]	[0.228]	[0.173]
Hansen Test	29.36	13.69	25.3	25.84	27.71	22.55
	[0.966]	[0.396]	[0.151]	[0.309]	[0.149]	[0.126]
Wald Test	128516.67***	353.93***	6234.02***	709949.2***	104446.29***	5849.14***
Obs	270	240	270	240	270	240

*[] Denotes the corresponding Z value and () represents the corresponding value of p. *p value < 0.10, **p value < 0.05, ***p value < 0.01.*

capability. Therefore, in the first section below, the direct effects of FDI and foreign trade on China's regional innovation capability are tested, while in the second section, the interaction between institutional quality and three international technology spillovers is added to preliminarily test the regulatory effect of institutional quality. In the third section, the dynamic threshold panel model is introduced to further test the spillover effect of international technology under different institutional quality conditions.

Direct Effect Analysis

Based on the panel data of 30 provinces in China from 2010 to 2019, the regression analysis of models (1) to (3) is carried out, and two-step SYS-GMM and two-step DIF-GMM are used to estimate the models, respectively. The results are shown in **Table 4**. It can be found that AR (2) test results show that there is no second-order sequence correlation in the random error term of the model, and Hansen test results show that the selection of model tool variables is effective. The Wald test results show that the overall height of the model is significant, so the regression results of SYS-GMM and DIF-GMM are reliable. At the same time, the direct effect estimation results also reflect the following problems.

Foreign direct investment and foreign trade have significantly promoted the improvement of China's green innovation capability, and their coefficients are all significantly positive at least at the level of 1%. The reason is that compared with the local enterprises in the host country, FDI enterprises usually have certain ownership advantages, and FDI with advanced technology has the potential for technology spillover (Khachoo et al., 2018). This will produce positive external spillover effects in the host country in four ways: demonstration effect, competition effect, personnel flow, and industrial correlation effect, thus promoting the technological progress and efficiency of the host country's enterprises. OFDI enterprises can learn from the leading technology of local enterprises and absorb the local technology spillover when making international investments abroad. The subsidiaries carry out local technological innovation and realize technological progress, and then use various ways to introduce technology to the home country to realize reverse technology spillover. However, foreign trade technology spillovers often acquire knowledge useful to our country through international trade, technology exchange, and other activities. This is a good way for developing countries and regions to gradually narrow the economic gap with developed countries (Wu et al., 2019). The larger the foreign trade volume, the more contacts among countries (regions). These contacts will promote the exchange of technical information among regions and help trade importing countries to get some new innovations from these technologies. It is beneficial for foreign demanders to put forward improvement suggestions on the production process of exported products to promote the improvement of domestic green innovation ability.

Analysis of Interaction Effect

Two-step SYS-GMM and two-step DIF-GMM are used to estimate models (4)–(6) after the interaction term is added. **Table 5** interaction effect estimation results show that there is no second-order sequence correlation in the residual series, tool variable selection is effective, and the model is significant as a whole. As for the regulation effect model of system quality, the interaction coefficient between the three kinds of international technology spillovers and various institutional quality is significantly positive, which indicates that institutional quality will affect the determinant coefficient of international technology spillover on China's green innovation capability. That is, the higher the quality of China's system, the more favorable it is for FDI and foreign trade technology spillover. The reasons are as follows: in terms of the regulatory effect of institutional quality on FDI, first, a good institutional environment improves the efficiency of capital allocation and reduces the entry cost of FDI, which is not only conducive to the entry of foreign capital in quantity but also conducive to the entry of technology-oriented FDI in quality, and promotes the transformation and upgrading of China's foreign capital structure (Urban, 2010). In addition, regions with higher institutional quality create a good institutional environment for the emergence of the FDI technology spillover effect, and the emergence of the FDI technology spillover effect provides a possibility for the improvement of China's green innovation capability (Hao et al., 2020). Second, the high-quality institutional environment has stimulated the vitality of the regional market to gain profits in the fierce market competition, local enterprises will continue to increase R&D investment and enhance green innovation ability. The improvement of the innovation ability of local enterprises provides the possibility of absorbing FDI technology spillovers. At the same time, a high-quality institutional environment is conducive to the flow of regional technical personnel and provides favorable opportunities for FDI enterprises to spread technology and local enterprises to imitate and innovate, thereby promoting green innovation ability. In terms of the regulatory effect of institutional quality on OFDI, first, the implementation of the strategy of "invigorating the country through science and education" and "strengthening the country with talents" has promoted the improvement of China's innovation ability and potential, which not only lays the foundation for the emergence of technology-oriented OFDI but also provides rich human capital for the home country enterprises to absorb the OFDI reverse technology spillovers. Second, the regions with higher system quality have an efficient financial market and an open market environment, and the policy support of the "going out" strategy not only provides convenience for OFDI enterprises to finance and invest but also helps them to integrate into a global value chain, participate in international market competition, and create conditions for technology seeking OFDI enterprises to absorb foreign advanced technologies (Chu et al., 2018). Third, the regions with higher system quality have a perfect management system, which is not only conducive to the management of OFDI multinational enterprises and reducing their operating costs but also provides institutional support for the return of technical personnel of overseas subsidiaries of OFDI enterprises, and creates a good institutional environment for promoting the green innovation ability of home countries. As far as the regulatory effect of institutional quality on foreign trade is concerned, for a long time, China's technological progress is dominated by technological innovation and technology introduction. High-quality intellectual property protection can prevent patent infringement. It can not only protect high-tech imported products but also promote the increase of their quantity to a certain extent. By learning and imitating imported products with advanced technology, Chinese enterprises can promote the production of new technologies and new processes and improve their technological innovation ability. At the same time, regions with a high level of intellectual property protection provide institutional support for technology-oriented export enterprises to obtain high export trade profits and encourage domestic enterprises to increase research and development and investment in high-tech products, to promote China's green innovation ability.

Dynamic Threshold Effect Analysis

Threshold Effect Test and Threshold Value Determination

Using Stata15 and based on the dynamic threshold panel model Wald test self-sampling method (bootstrap), the significance test of threshold effect with FDI, OFDI, and foreign trade as the core explanatory variables is conducted under the assumption of no threshold effect. From Wald statistics and its *p*-value, we can see that the dynamic threshold models with three different international technology spillovers as the core explanatory variables all rejected the original hypothesis of no threshold effect at the significance level of 1% (as shown in **Table 6**). This shows that the impact of international technology spillovers on regional green innovation capability is nonlinear due to the difference in institutional quality among provinces and regions.

Parameter Estimation and Result Analysis

The threshold effect estimation results show (**Tables 6**, **7**) that the positive effects of three kinds of international technology spillovers on green innovation capability all increase with the improvement of China's institutional quality. Therefore, the

TABLE 5 | Regression results of interaction effects.

Variable	Model 4		Model 5		Model 6	
	SYS-GMM	DIF-GMM	SYS-GMM	DIF-GMM	SYS-GMM	DIF-GMM
$lngcreate_{it-1}$	0.802***	0.400***	0.790***	0.444***	0.795***	0.576***
	(76.64)	(5.46)	(50.57)	(7.42)	(16.29)	(35.70)
lnrdp	0.328***	2.242***	0.349***	2.013***	0.361***	1.107***
	(14.81)	(11.48)	(19.66)	(12.44)	(5.44)	(47.65)
lnrd	18.438**	−59.742	16.267***	−69.096*	88.804*	1.426
	(2.17)	(−1.43)	(2.73)	(−1.93)	(1.95)	(0.24)
lnhum	−1.075***	−5.205***	−1.285***	−4.263***	−0.055	−3.712***
	(−5.71)	(−5.31)	(−7.12)	(−5.50)	(−0.13)	(−10.89)
lnind	−18.313**	59.545	−16.045***	68.620*	−88.700*	−2.003
	(−2.16)	(1.42)	(−2.70)	(1.90)	(−1.95)	(−0.34)
lnfdi	0.084***	0.130***				
	(3.79)	(1.88)				
inst × lnfdi	0.089***	0.290***				
	(3.27)	(3.62)				
lnofdi			0.133***	0.138***		
			(3.07)	(2.00)		
inst × lnofdi			0.164***	0.141*		
			(4.20)	(1.89)		
lntrade					0.082***	0.466***
					(2.03)	(2.37)
inst × lntrade					0.198**	0.292***
					(2.39)	(11.26)
_cons	3.464***		4.016***		1.349*	
	(9.78)		(11.65)		(1.86)	
AR(2)	1.45	0.01	1.60	0.19	−0.27	0.96
	[0.147]	[0.992]	[0.11]	[0.848]	[0.788]	[0.338]
Hansen Test	29.45	19.49	27.57	23.33	27.7	3.77
	[0.928]	[0.301]	[0.981]	[0.273]	[0.426]	[0.438]
Wald Test	118312.07***	997.17***	59061.49***	1980.62***	16983.97***	26723.52***
Obs	270	240	270	240	270	240

*[] Denotes corresponding Z value and () represents corresponding value of p. *p value < 0.10, **p value < 0.05, ***p value < 0.01.*

TABLE 6 | Self-sampling test of a dynamic threshold effect.

Core explanatory variable	Model	Threshold value	Wald statistic	*P*-value	BS times	95% confidence interval	
FDI	SYS-GMM	0.326	16.008***	0.000	1000	0.058	0.442
	DIF-GMM	0.085	55.380***	0.000	1000	0.058	0.442
OFDI	SYS-GMM	0.357	36.560***	0.000	1000	0.058	0.442
	DIF-GMM	0.430	222.818***	0.000	1000	0.058	0.442
Trade	SYS-GMM	0.442	118.123***	0.000	1000	0.058	0.442
	DIF-GMM	0.085	1.130***	0.000	1000	0.058	0.442

****Significant at the level of 1. P-value and critical value are obtained by repeated sampling of the GMM threshold panel regression program for 1,000 times. Wald statistic is used to judge whether the threshold feature is obvious. The smaller the corresponding probability, the more obvious the threshold feature is.*

international technology spillover effect is more obvious in regions with high institutional quality, which is consistent with the previous conclusion of the interaction effect. Specifically, with FDI as the core explanatory variable, if the regional system quality is lower than the threshold value of 0.326, the green innovation ability will increase by 0.090% for every 1% increase in FDI, and 0.105% for every 1% increase in FDI when the regional system quality is higher than the threshold value of 0.326. For OFDI technology spillovers, if the regional institutional quality is lower than the threshold value of 0.357, the green innovation ability will increase by 0.046% for every 1% increase in OFDI, and if the regional institutional quality is higher than the threshold value of 0.357, the OFDI will increase by 1%. Then, the green innovation ability will be improved by

TABLE 7 | Dynamic threshold regression results.

Variable	Model (1)		Model (2)		Model (3)	
	SYS-GMM	DIF-GMM	SYS-GMM	DIF-GMM	SYS-GMM	DIF-GMM
lngcreate$_{it-1}$	0.856***	0.358***	0.819***	0.476***	0.977***	0.605***
	(89.83)	(11.84)	(87.54)	(39.86)	(50.62)	(4.02)
lnrdp	0.185***	1.645***	0.208***	0.727***	0.046	1.214***
	(19.12)	(20.31)	(13.69)	(21.91)	(0.84)	(5.51)
lnrd	−0.290***	0.183**	0.187***	0.028***	0.105	−0.015
	(−1.78)	(2.16)	(7.37)	(3.13)	(1.19)	(−0.48)
lnhum	−1.466***	−2.388***	−0.619***	−0.055	−2.751***	−6.704***
	(−6.16)	(−5.17)	(−3.96)	(−0.21)	(−5.80)	(−3.74)
lnind	−0.290*	−2.685***	0.187***	−1.018***	0.005	4.314**
	(−1.78)	(−11.92)	(7.37)	(−5.43)	(0.03)	(2.44)
$lnfdi \cdot I(inst \leq C)$	0.090***	0.233***				
	(12.01)	(9.22)				
$lnfdi \cdot I(inst \geq C)$	0.105***	0.919***				
	(13.76)	(11.26)				
$lnofdi \cdot I(inst \leq C)$			0.046***	0.115***		
			(4.43)	(8.76)		
$lnofdi \cdot I(inst \geq C)$			0.056***	0.165***		
			(8.44)	(10.16)		
$lntrade \cdot I(inst \leq C)$					0.076	0.747***
					(1.59)	(4.05)
$lntrade \cdot I(inst \geq C)$					0.095*	0.797**
					(1.86)	(3.66)
_cons	4.018***		2.637***		5.981***	
	(8.76)		(8.22)		(7.00)	
AR(2)	1.05	1.44	1.43	1.57	1.43	1.65
	[0.294]	[1.149]	[0.153]	[0.117]	[0.153]	[0.099]
Hansen Test	27.91	28.16	28.6	27.47	27.76	7.16
	[0.979]	[0.852]	[0.955]	[0.814]	[0.583]	[0.711]
Wald Test	76526.19***	6298.16***	103958.31***	25143.82***	50292.64***	605.69***
Obs	270	240	270	240	270	240

*[] Indicates the corresponding Z value and () indicates the corresponding value of p. *p value < 0.10, **p value < 0.05, ***p value < 0.01.*

0.056%. For foreign trade technology spillover, if the regional system quality is lower than the threshold value of 0.442, there is no obvious technology spillover effect. When the regional system quality is higher than the threshold value of 0.442, the regional innovation ability will increase by 0.095% for every 1% increase in foreign trade. International technology spillovers from three different channels in areas with low system quality, FDI has the largest technology spillover effect, followed by OFDI. In regions with high institutional quality, the technology spillover effect of FDI is the largest, followed by that of foreign trade and OFDI.

CONCLUSION AND POLICY RECOMMENDATION

In this article, the provincial panel data of China from 2010 to 2019 are used to measure the quality of China's provincial system, and the system quality evaluation system is constructed by the method of fully arranged polygon graphic indicators, which is used as the adjustment variable to join the model. A dynamic panel model and a dynamic threshold panel model are used to test the direct effect, system quality interaction effect, and threshold effect of FDI and foreign trade spillover on green innovation capability. The results show that the three technology spillovers have significantly promoted China's green innovation capability. System quality will affect the determining coefficient of international technology spillovers on China's green innovation capability. The positive promoting effects of FDI and foreign trade on China's green innovation capability all increase with the improvement of China's system quality. In view of the above conclusions to use international technology spillover to promote China's green innovation capability, this article puts forward the following suggestions:

First, continuously increase infrastructure construction, improve laws and regulations, continue to expand investment attraction, and create a good institutional environment for the continuous entry of FDI and its technology spillover. In the process of introducing foreign capital, the government should change the evaluation standard of heroes based on quantity theory, establish a performance evaluation system based on technology-oriented FDI introduction, and gradually improve the quality of FDI introduction. Constantly deepen reform and opening up, market-oriented, stimulate market vitality, and force enterprises to carry out green innovation ability with highly active market competition environment. Attach great importance to education, improve the level of regional human capital, and promote the absorptive capacity of local enterprises to FDI spillover technology (Wang, 2007; Deng et al., 2018). Liberate and relax the system of human resource management, promote the free flow of technical personnel in enterprises, and give full play to the effect of personnel mobility to promote technology dissemination. Second, continue to implement the strategy of "rejuvenating the country through science and education" and "strengthening the country through talents," increase investment in science and technology and education, promote the innovation ability of the home country, and create conditions for the generation of technical OFDI in the home country. Intensify the reform of the financial market, improve the efficiency of the financial market, and provide a good financing environment for OFDI enterprises. Increase investment in developed countries, encourage technology-seeking OFDI, focus on investment in high-tech industries, and further optimize OFDI investment structure. Promote enterprise management innovation, promote the management level of multinational companies, and create favorable conditions for OFDI enterprises to return overseas technicians. Third, continue to implement the basic national policy of "opening to the outside world." Adhere to the combination of "bringing in" and "going out" to expand the import and export trade volume. Improve the intellectual property protection system, encourage technological innovation of local enterprises, give policy support to technology-oriented export enterprises, and reward the export of high-tech products. Increase the import proportion of technology-oriented products and encourage Chinese enterprises to digest, absorb, and re-innovate foreign advanced technologies. Broaden communication channels at home and abroad, take customer demand as the guide, and constantly improve the added value of export products.

Although this article studies the relationship between international technology spillovers, institutional quality, and green innovation, provincial panel data are used as research samples. Future research may need to use urban data or enterprise data to get more accurate results.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

TW contributed to conceptualization, writing—original draft, and methodology. YD contributed to supervision. KG contributed to formal analysis. RS contributed to variable construction. CW contributed to funding acquisition. BY contributed to data handling. All authors have read and agreed to the published version of the manuscript.

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Nexus Between Financial Development, Renewable Energy Investment, and Sustainable Development: Role of Technical Innovations and Industrial Structure

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Significant challenges confronting China include reducing carbon emissions, dealing with the resulting problems, and meeting various requirements for long-term economic growth. As a result, the shift in industrial structure best reflects how human society utilizes resources and impacts the environment. To meet China's 2050 net-zero emissions target, we look at how technological innovations, financial development, renewable energy investment, population age, and the economic complexity index all play a role in environmental sustainability in China. Analyzing short- and long-term relationships using ARDL bounds testing, we used historical data spanning 1990–2018. According to the study's findings, the cointegration between CO_2 emissions and their underlying factors was found. The deterioration of the environment directly results from financial development, increasing economic complexity, and population aging. Technical advancements, investments in renewable energy sources, and changes to the industrial structure all contribute to lower CO_2 emissions. Granger causality results were also reliably obtained in this study. According to our findings in the fight against environmental problems, a key tool for meeting long-term sustainability goals is policy prescriptions that use technological innovations, renewable energy investment, and industrial structure.

Keywords: technical innovations, industrial structure, renewable energy investment, sustainable development, China, financial development

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INTRODUCTION

Academics, industry representatives, and policymakers pay growing attention to sustainable development (SD) (Nureen et al., 2022). The discussion on SD has touched on many different topics, but one of the most important is how innovations can help improve sustainability (Majumder et al., 2019). Because both the external environment and the way we live are subject to constant change (see here for more information), innovations are essential components that must be present for businesses, institutions, regions, communities, and countries to implement sustainable practices (Kouhizadeh et al., 2019). The body of academic research agrees that innovative methods should be prioritized when addressing the issue of sustainability (Iqbal et al., 2019). Changes toward a more sustainable world are moving slowly in reality. There are urgent calls for institutions of higher learning and governments to step up their investments and initiatives to find new and creative solutions to our environmental challenges (Huang et al., 2019).

The Brundtland Commission's seminal definition of sustainable growth emphasizes the interdependence between sustainability's financial (Chen et al., 2021; Quan et al., 2021) and environmental aspects. Asikha et al. (2021) suggest that equal consideration should be given to economic, environmental, and communal dimensions when making business and public policy decisions. According to the findings of some studies (Ahmed and Omar, 2019; Adedoyin et al., 2021; Fahria et al., 2021), the discussion of sustainability has expanded beyond the relationship between environmental and economic parameters to include the effects on society as well. Similarly, Chen et al. (2022) acknowledge the need to analyze the complex interactions between all three dimensions. They conclude that the ever-changing nature of sustainability calls for a process of adaptation that requires the active participation of all relevant stakeholders (Geissdoerfer et al., 2018; Deng and Zhao, 2022; Xu et al., 2022). This introductory article and the study contribute to reducing the current knowledge gap in this field. This is because different studies have different definitions of innovation for sustainable development.

China has experienced phenomenal economic growth over the last few decades, thanks to the country's quickening pace of industrialization. China is currently one of the most important manufacturers worldwide. On the other hand, noteworthy economic accomplishments have been accomplished at the expense of the environment and by consuming an excessive amount of energy. Industrial activities account for more than two-thirds of China's total energy consumption, making it the world's major consumer of power and carbon emissions emitter (He X. et al., 2021). Energy efficiency in industrial systems is critical to developing a low-energy, environmentally responsible, and sustainable system.

Major shifts in global energy consumption and industrial structures are taking place as urbanization and industrialization continue to progress and become more advanced (Wu and Zhu, 2021; Lei et al., 2022). The position of Asia as the primary contributor to global energy consumption is shifting (Hou et al., 2019). Changes in energy consumption bring about the improvement of environmental conditions. However, accomplishing this transformation remains challenging due to the difficulty of reorganizing subsidies for the consumption of fossil fuels and supply risks concerning the supply of oil and gas (Falcone et al., 2018). The achievement of long-term reductions in CO_2 emissions presents a formidable obstacle. After 3 years of stagnant growth, the world's energy-related carbon dioxide emissions raised by 1.7% in 2017 (Salari et al., 2021). In addition, it is anticipated that they will continue to expand in the coming years, which is a significant departure from the requirements set forth by climate change targets. According to the Fifth Report given by the Intergovernmental Panel on Climate Change (IPCC), greenhouse gases in the atmosphere steadily rise yearly. Since 1750, there has been a 40% increase in the concentration of CO_2, which has resulted in levels of CO_2 that have never been seen before (Awaworyi Churchill et al., 2020). According to the projections made by the International Energy Agencies, the amount of carbon dioxide released into the atmosphere due to energy use will reach a maximum around the year 2020. However, it is a fact that global carbon emissions, particularly those that result from Asia, will either remain unchanged or even slightly increase by the year 2040. This prediction is based on objective data. In addition, ~95% of the total allowable emissions to meet global climate targets have already been accounted for by current emissions (Xiao et al., 2021). As a result, governments, international organizations, experts, and academics will continue to focus on the issue of carbon emissions and carbon reduction for the foreseeable future. Sustainability at the global and regional levels depends on achieving green ecological development by cutting back on energy use, pollution, and emissions in these areas. Reduced energy use, pollution, and emissions are part of this solution.

One of the most prevalent topics of conversation in contemporary research is the development of new methods for preserving the quality of the environment, cutting carbon dioxide emissions, and raising production levels (Yu et al., 2022). The application of novel concepts constitutes innovation. Product and organizational innovation are distinct subcategories of innovation that can be distinguished from one another (Klarl, 2020). Despite the positive effects of innovation on production growth and cost reduction, it also has a deleterious influence on energy usage and carbon dioxide emission. The most significant benefit that can be reaped from innovation is a cut in carbon dioxide emissions, which can be accomplished without hampering economic expansion (Wang J. et al., 2019). The price of energy can be reduced with the help of recently developed products that use less. To put it another way, increased production can be achieved while maintaining the same level of energy consumption. The topic of energy efficiency is brought to people's attention by research that focuses on how innovation lowers carbon emissions (Ben Cheikh et al., 2021).

The introduction of new technologies has two significant repercussions. The first effect is a reduction in wasted energy. The second effect is that there will be a greater requirement for more energy because the same activity will be carried out using less energy. While reducing carbon emissions and fuel consumption is a top priority, the rebound effect must be properly considered. Blondeau and Mertens (2019) claim that developing countries are particularly susceptible to the problem of a rebound effect. In order to determine if this problem exists in other countries and developing nations, further research must be done.

As a result, the focus of this paper will be on the impact that technological innovations have on the path that technological change takes, and the low-carbon technology will be divided into clean technology and gray technology. Within the scope of this investigation, the following research questions about technological advancements will be posed: (1) Is it possible for TI to develop into a useful tool for guiding technological advancement? (2) Does TI have an effect on economies that produce less carbon? In an effort to answer these questions, this study has contributed to the existing body of research in the four areas listed below, all of which pertain to the association between technological innovation and a sustainable environment. In the first step of this project, we will extend the research that has already been done on technical innovations for low-carbon economies in China. We will answer how this factor can affect the total amount of emissions. This study investigates the link between financial development and sustainable development by using domestic credit to the private sector as a proxy. As a second point, this paper makes new contributions to the existing literature on financial development and sustainable development. Investment in renewable energy sources can cause reductions in carbon emissions; however, which of these two strategies is more effective in bringing down emissions levels? This article attempts to answer the research question does renewable energy investment (REI) reduce carbon emissions? To investigate REI's effect on emissions, we will have a quick conversation about investments in renewable energy. Moreover, to investigate the suggested objectives, this study chose the time period from 1990 to 2018. The data has been selected in recent years due to data availability. Hence this study uses the mentioned time period to deliver its objective. In addition, the ARDL methodology is applied in this study to estimate the concerned objective of the study.

LITERATURE REVIEW

Nexus of Financial Development and Environment Quality

Several studies have observed the link between economic growth and pollution, and what they've found is summarized here. Based on the findings of the studies, empirical literature can be divided into three main subfields (Mutascu, 2018). Carbon emissions have been linked to economic growth in the first section of this discussion. A random-effect model examined financial development in the BRICS countries. When it comes to the stock market, financial openness, the deposit money bank asset-to-GDP ratio, capital account convertibility, financial liberalization, and FDI, researchers found that a decrease in carbon emissions goes hand in hand with a rise in fiscal development. Carbon emissions in 24 transitional economies were studied by You and Lv (2018) using a new random effect model and dynamic GMM. They concluded that freeing the financial system positively affected the environment. Ma et al. (2019) used the cointegration method to observe the carbon emissions of 129 countries. According to their findings, carbon emissions can be reduced by increasing the amount of domestic credit available to the private sector—results from an investigation into the influence of financial development on carbon emissions by Adebayo et al. (2021a) and Ojekemi et al. (2022) were encouraging. Higher loan-to-deposit ratios are linked to lower carbon emissions. In China, the research was conducted.

According to Khan et al. (2019), financial development, specifically domestic credit to the private sector, takes part in reducing carbon emissions in Malaysia. This study's goal was to show that financial growth has a negative effect on carbon dioxide emissions. ARDL was used by Jalalian et al. (2019) to find that financial development, as measured by stock market incomings, total credit, private sector credit, and stock market capitalization, reduced carbon emissions in Pakistan and during the period of financial liberalization. During the time frame under consideration, this was discovered to be true. Liu et al. (2019) used ARDL to study the impact of China's financial development on carbon emissions. Financial development has reduced carbon emissions as measured by the ratio of liquid liabilities and private sector loans to GDP. It was crucial to look at the ratio of private sector loans to GDP to determine whether financial development affected carbon emissions. Financial stability in Pakistan, India, Nepal, and Sri Lanka has been found to improve the environmental quality of these countries, and financial stability unidirectionally causes carbon emissions in these countries. These and other nations are included in the research (Shahbaz and Sinha, 2019; Aydogan and Vardar, 2020).

In addition, Jalalian et al. (2019) used ARDL to investigate the impact of China's financial development on the country's carbon emissions. They concluded that China's financial development has a negative impact on carbon emissions. Zubair et al. (2020) used GMM to examine the influence of financial growth on carbon emissions in China. The investigation showed that the intensity of carbon emissions was reduced when financial development was measured by the ratio of bank loans to GDP, private loans to GDP, and non-private loans to GDP. These ratios were all compared to GDP. Using ARDL, Adams et al. (2020) concluded that domestic credit provided by banks from the private sector to the private sector as part of financial development helps reduce emissions produced by the construction industries in Malaysia. A separate piece of research (Aydogan and Vardar, 2020) investigated the connection between carbon emissions and financial development in Turkey. They concluded that in the short term, at least, financial development leads to lower levels of carbon emissions.

A positive effect of financial development on carbon emissions is reported in the second part of the empirical studies used VECM and ARDL to examine the effects of financial development on carbon emissions in India. They concluded that financial development (credit to the private sector) increases carbon emissions. Aydogan and Vardar (2020) published their findings in Environmental Research and Development Letters. In India, Boutabba (2014) discovered that through the use of ARDL and the Granger causality test, financial development (domestic credit to the private sector) leads to an increase in carbon emissions and a uni-directional causal connection between financial development and carbon emissions. Al-mulali et al. (2015) also examined the effect of China's rapid financial development using the cointegration and causality approach. He discovered that the indicators of rapid financial development are the primary drivers of carbon emissions. According to Nyoka (2019), an increase in financial development—defined as domestic credit extended by banks to the private sector—leads to increased carbon emissions from the transportation, oil, and gas sectors.

Carbon emissions rise when financial depth (the ratio of loans and deposits to GDP) rises, according to a study by Razmjoo et al. (2021) using the system-GMM. The researchers also discovered a U-shaped link between carbon emissions and economic development. Using a system-generalized method of moments, Acheampong (2019) investigated the indirect and direct effects of financial development on carbon emissions for 46 countries in sub-Saharan Africa between 2000 and 2015. The countries in this study were divided into two groups: those with high levels of financial development and those with low levels. According to the study results, financial development, as measured by domestic credit to the private industry, broad money, and domestic credit by banks, all contribute to increased carbon emissions. Carbon emissions aren't affected by foreign direct investment, liquid liabilities, or domestic credit from the financial sector. Although FDI has been found to moderate economic growth, which reduces carbon emissions, it does not moderate power usage, which has no impact on CO_2 emissions, according to the study's findings. Contrary to the first three financial development indicators (i.e., broad money), financial development (i.e., domestic credit by banks and the financial sector) regulates energy consumption to increase CO_2 emissions. For 122 countries, Razmjoo et al. (2021) used FMOLS and DOLS to observe the impact of financial development on carbon emissions from 1990 to 2014. They found that the overall sample's carbon emissions worsened as financial development progressed. Environmental Research Letters published their findings. According to the research, a decrease in carbon emissions was observed in countries with high incomes; on the other hand, a rise in emissions was observed in countries with low and middle incomes.

The most recent collection of empirical studies found no significant link between the growth of the financial sector and increases in carbon emissions. In their study, Kacprzyk and Kuchta (2020) utilized system-GMM to investigate the impact of a country's financial development level on its carbon emissions in 12 MENA nations. According to their findings, the expansion of financial resources (credit to the private sector) does not influence levels of carbon emissions. A study conducted using OLS and causality analysis (Abokyi et al., 2019) examined the impact of financial development on carbon emissions in 40 European countries. They concluded that financial development, defined as domestic credit provided by banks to private sectors, does not negatively impact carbon emissions. In a separate piece of research, Zubair et al. (2020) used ARDL to examine the relationship between the state of the nation's financial system and the country's total carbon emissions. According to the findings of their study, there is no evidence of a causal connection between the expansion of the domestic credit market to the private sector and increases in carbon emissions. According to Tan et al. (2021) research, domestic credit provided by banks to the private sector as part of financial development has a negligible effect on agriculture emissions in Malaysia's context. According to the findings of Acheampong et al.'s (2019) most recent research, economic growth causes an increase in carbon emissions in Australia, Brazil, and China, while it results in a decrease in carbon emissions in the United States and India.

Nexus of Technical Innovations and Environment Quality

In terms of the pollution caused by carbon dioxide emissions, studies investigating the association between innovation and those emissions have been encouraging. Salari et al. (2021) conducted research in Malaysia covering 1985–2012 to investigate the correlation between technological advances and carbon dioxide emissions. Using causality analysis, researchers found a two-way causality between CO_2 emissions and financial growth and between Carbon dioxide emission and technological innovation over the long term. This link between cause and effect can be observed in the short and long term. A more positive outlook for the environment was provided by investing in cutting-edge technologies that were also environmentally friendly (Yuping et al., 2021). Twenty-four countries were studied by Khan and Rana (2021), which looked at the relationship between CO_2 emissions and economic development between 1980 and 2010. The study spanned the years 1980–2010. The study found a connection between long-term increases in CO_2 emissions and increases in economic growth, but this connection does not exist in the short term. Additionally, it was discovered that technological advances were responsible for a portion of the decrease in CO_2 emissions (Awosusi et al., 2022b).

Between 1990 and 2017, Mehmood (2021) found that environmental innovations in the BRICS countries influenced CO_2 emissions efficiency and production-based energy usage. The findings of the tests indicate that technological advancements in BRICS states have a substantial impact on the amount of energy consumed and the emissions of carbon dioxide. According to the findings, investments in development and research led to decreased carbon emissions, which was the study's focus. Awosusi et al. (2022a) conducted research to determine the influence of environmental innovations on Italian regions' level of environmental efficacy from 2002 to 2005. The experiential findings demonstrate that improvements in environmental competence are more satisfying in industries with a high level of adoption of environmentally friendly technologies. Pejović et al. (2021) conducted research in the United States covering the years 1963–2010 to investigate the effect of economic growth, technological advancement, and CO_2 emissions on each other over the long term. According to empirical research findings, a rise in income is accompanied by a fall in CO_2 emissions due to technological advances in production. Increases in revenue and technological advancement can have a detrimental impact on the strength of CO_2 emissions. He K. et al. (2021) made an effort to establish whether or not the pursuit of innovation benefits the level of carbon dioxide emissions. Their research used information about research and development and energy usage from China, the European Union, and the United States between 1990 and 2013. The study's findings support the hypothesis that developed countries' expenditure on research and development is positively linked with lower levels of carbon dioxide emissions.

Investment in R&D has been found to be an important factor in both economic growth and the attainment of sustainable development goals (Adebayo et al., 2021b, 2022; Awosusi et al., 2022a). This was a discovery that the National Science Foundation made. Kang et al. (2019) investigated the connection between innovative practices and CO_2 emissions in 28 countries members of the OECD from 1990 to 2014. The research concluded that innovation plays a significant role in lowering CO_2 emissions in most OECD countries. Luo et al. (2020)

conducted research on the primary factors that determine CO_2 emissions and the connection between them for France. According to the writers, increasing public investment in energy research and development has decreased CO_2 emissions. From 2003 to 2017, Li W. et al. (2021) studied the connection between innovation, economic expansion, and CO_2 emissions in the most innovative countries. The United States, India, China, France, Japan, Italy, the Republic of Spain, Korea, and the United Kingdom were all included in the study. According to the findings, many factors can reduce CO_2 emissions. These factors include high-tech exports, innovation, R&D expenses, and environmental taxes. Populace size and the price of the solar system are both factors that can increase CO_2 emissions.

Işik et al. (2017) conducted research to determine China's high-tech industry had on the country's total CO_2 emissions. According to the findings of the tests, sectors contributing to low carbon emissions and energy efficiency make use of advanced technological processes. As a result, it was discovered that the technology industry was successful in lowering CO_2 emissions and fostering the transition to a low-carbon budget. Martinell et al. (2021) investigated the agglomeration effect of CO_2 emissions and the effect of industrial growth on China's efforts to lower CO_2 emissions from 2001 to 2015. Their study covered the period from 1984 to 2016. Considering the data from the patents, it was discovered that factors in China have a beneficial effect on developing new technologies, conserving energy, and reducing CO_2 emissions. Piaggio et al. (2017) conducted research on the connection between the amount of electricity used, CO_2 emissions, R&D stocks, and economic development for Mediterranean nations from 1990 to 2016. According to empirical research, a one-way causality relationship was seen between CO_2 emissions and R&D stocks. Even though robust feedback effects exist between economic growth, CO_2 emissions, and electricity consumption, this was the case. Le et al. (2020) conducted research to investigate how innovation and technological investment affect CO_2 emissions in OECD countries from 2000 to 2014. The time period covered was from 2000 to 2014. The following are some of the most important conclusions that the authors have reached regarding the connection between CO_2 emissions and innovation: There is a mathematically significant inverse relationship between the amount of money spent on R&D and the amount of carbon emissions. A correlation can be considered significant between the number of patents and the amount of carbon emissions. Shen et al. (2021) investigated whether or not domestic innovation in Turkey helps slow the rate of environmental degradation. They looked at the association between innovation and CO_2 releases from 1971 to 2013 and found some interesting results. The findings indicate a relationship in the shape of an inverse U between the level of CO_2 emissions and the number of domestic patents. On the other hand, there appears to be a non-linear connection between the amount of CO_2 emissions and innovation within the country. Anser et al. (2020) investigated the impact of eco-innovation on reducing carbon dioxide emissions in the top twenty countries in terms of refined oil exports between 2007 and 2016. The findings indicate that eco-innovation has a negative effect on carbon dioxide emissions. Researchers (Duro et al., 2020) analyzed the impact that innovation shocks had on CO_2 emissions in twenty-six countries members of the OECD between 1996 and 2014. The authors concluded that disruptive innovations have a negative impact on environmental quality. Alternatively, it was emphasized that any decrease in innovation activities and strategies would lead to a rise in CO_2 emissions. This point was driven home repeatedly.

Ma et al. (2019) conducted research to investigate the relationship between China's energy consumption rate and its rate of technological advancement in the energy sector from 2005 to 2016. The development of energy technologies and the rate at which they emit carbon dioxide has an inverse U-shaped relationship. Eighteen developed and six developing countries were included in the study (Khan et al., 2019) to investigate the association between innovation, CO_2 emissions, and economic development from 1990 to 2016. An examination of panel data reveals a correlation between higher energy usage and CO_2 emissions. The authors concluded that innovation had a mixed result. In the G6 countries, innovation leads to a reduction in CO_2 emissions, but it leads to a rise in CO_2 emissions in the BRICS and MENA countries.

Nexus of Renewable Energy Investment and Carbon Emissions

Administrations have utilized mandatory and incentive mechanisms to boost utility corporations to finance renewable energy. These are the two primary mechanisms that have been utilized (such as subsidies and carbon taxes). In the research that has been done, various obligatory mechanisms have been debated. The mechanism known as the feed-in tariff ensures returns for investors (Cheng et al., 2019). According to the findings of Iqbal et al. (2022), the investor should invest in renewable energy during the present period if the profit will decrease over time; however, the investor should delay investment until a later period if the profit will increase at least somewhat for a later period. Shabir et al. (2022) analyze and contrasts the risks associated with two different pricing mechanisms: the fixed price mechanism and the premium price mechanism. They conclude that a fixed price mechanism can lessen the risks associated with the investment. Both (Raghutla et al., 2021) conducted research on the mechanism known as the renewable portfolio standard. They highlight that the electricity supply must contain a certain percentage of renewable energy under this mechanism. The feed-in-tariff mechanism, which sets a fixed price for electricity, and the renewable portfolio standard mechanism, which requires the utility company to generate a certain amount of renewable energy using mandatory methods, are distinct from the cap-and-trade is a market-based trading system.

Incentives and their associated mechanisms have also been examined in the research. Wang and Zhang (2020) investigate the rationale behind investing in renewable energy by comparing the costs and benefits of producing energy using renewable vs. non-renewable sources. They make the point that a tax on carbon raises the value of renewable energy sources, whereas an increase in carbon price may discourage investment in

TABLE 1 | Description of variables.

Variable	Unit	Source
Dependent variables		
CO_2	Carbon emission (Kt)	WDI
Explanatory variables		
FD	Financial development (domestic credit to private sector % of GDP)	WDI
TI	Research and Development expenditures (% of GDP)	WDI
IS	Industrial structure percentage of the added value of a third industry to GDP (% of total)	Statistics China
Control variables		
ECI	Economic complexity index	
REI	Renewable energy investment (USD Billions)	GTREI/ IRENA
PA	Population aging (65+)	WDI

renewable energy sources. In contrast to Wang et al. (2020), our research demonstrates that an increase in carbon price leads to an increase in investment in renewable energy. This is because renewable energy and conventional energy are interchangeable, whereas, in their paper, they are complementary. Because of this, according to our model, the utility company will be motivated to finance renewable energy whenever the price of carbon goes up. They show that investment in renewable energy is decreased (increased) if the government subsidizes inflexible (flexible) energy sourcing. They focus on how subsidizing conventional energy influences investment in renewable energy. Shahbaz et al. (2020) focus on how conventional energy subsidies influence investment in renewable energy.

Nexus of Industrial Structure and Carbon Emissions

Numerous researchers examined the association between the structure of industries and the amount of energy consumed from various vantage points and depths. According to researchers, adjusting the industrial structure is the primary method of reducing energy intensity (Jing et al., 2018). There have been many studies that have concentrated on the energy intensity of various subindustries (ref). According to Zhang et al. (2014), who studied the relationship between China's industrial structure and energy strength from 1980 to 2006, China ought to improve the utilization efficiency of coal and cut down on the energy it consumes from coal. In their study on the effect of varying conditions on energy intensity, Wang and Feng (2018) utilized a non-linear threshold cointegration method to conduct their research. Wang K. et al. (2019) used 283 cities to investigate how a city's internal industrial structure affects energy intensity at the city level. During China's 12th Five-Year Plan (FYP) Period, Yan and Su (2020) analyzed the driving force behind energy intensity and identified the key sectors considering the critical effects. The researchers (Chai et al., 2021) analyzed the change in energy intensity in China from 1997 to 2015 and concluded that an important driving force behind the decrease in energy intensity was an adjustment to the industrial structure. Because it did not take into account any of the other factors that went into production, energy intensity could not accurately reflect technical efficiency or substitution effects (Lin and Xu, 2020). Researchers started paying attention to the energy efficiency of industrial systems based on multiple inputs and outputs at about the same time (Feng and Wu, 2022). For instance, measured the energy efficiencies of Beijing's industrial sectors from 2005 to 2012 and found that there were differences between the various industrial sectors. Chen et al. (2017) analyzed the non-uniform inputs and outputs of various industrial sectors to determine the energy efficiencies of those sectors. Feng and Wu (2022) found that the structure of the industrial sector was the most important determinant of energy efficiency in the industrial sector.

Scholars have also conducted pertinent research regarding the relationship between the structure of industries and carbon emissions (Xu and Lin, 2016). Numerous studies concluded that the structure of industries played an important part in carbon emissions (Dong et al., 2018). Some researchers investigated how adjusting the structure of industries would affect the amount of carbon emissions. Xiong and Sun (2022) conducted their research on the effect of industry structure utilizing decomposition analysis. The convergence of industrial carbon intensity in China focused on research conducted by Wang et al. (2017). The effects of industrial structure on carbon intensity from city levels in China were analyzed by Wang and Yang (2020), and they concluded that the adjustment of the industrial structure had very little impact on the reduction of carbon intensity. Because carbon intensity was only one indicator of carbon efficiency, researchers started using other methods to study industrial carbon emissions' effectiveness. Du et al. (2019) investigated the effectiveness of the meta frontier non-radial Malmquist method in their research on the efficiency trends of carbon emissions. The authors of the 2013 study (Jia et al., 2019) investigated the effect that alternative energy policies had on the power industry in Europe. Li Z. et al. (2021) developed a new DEA method to evaluate the dynamic changes in the performance of carbon emissions. Tong et al. (2018) developed a method to investigate the carbon efficiencies of China's 30 provinces by combining cross efficiency with the Malmquist productivity index. This method was used to compare the provinces in order to determine which industries are the most effective at reducing their carbon footprint.

Literature Gap

From an empirical point of view, most previous studies (Zhao and Yang, 2020; Amin et al., 2022; Xiong et al., 2022) have investigated the impact of financial development and renewable energy on CO_2 emissions have employed either time series or panel data analysis. In addition, only a few studies have concurrently included technology innovation, renewable energy investment and financial development to assess their impact on CO_2 emissions. To the best of our knowledge, no studies in the empirical literature have examined this research question that accounts for the concurrent effects of technology innovation, renewable energy investment and financial development on

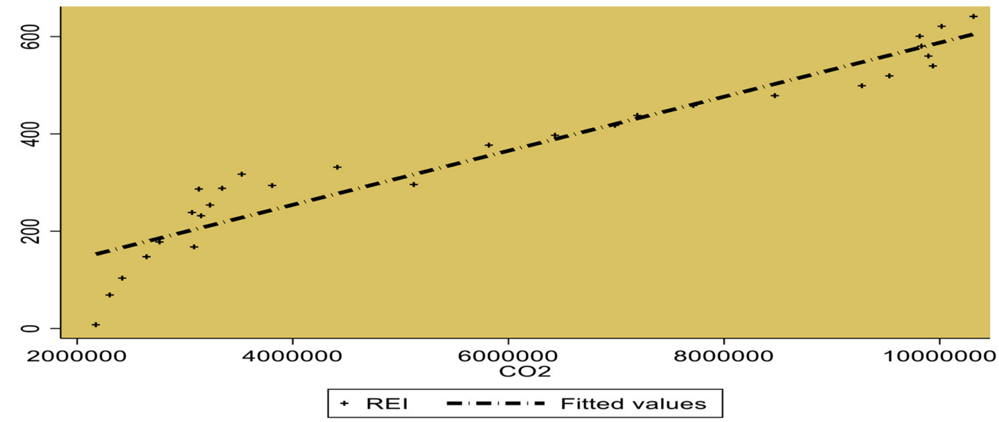

FIGURE 1 | Scatterplots of renewable energy investment vs. CO_2 emissions.

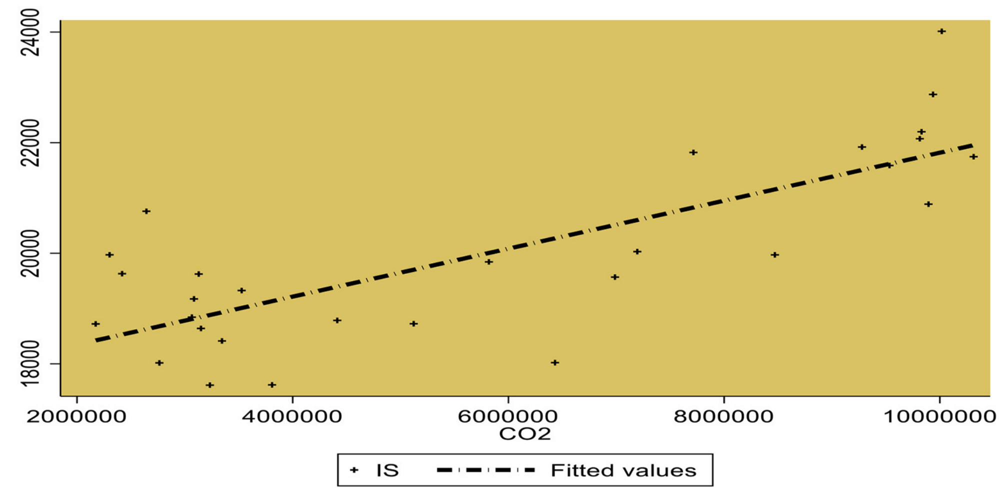

FIGURE 2 | Scatterplots of industrial structure vs. CO_2 emissions.

CO_2 emissions within the China framework. In addition, from an observational perspective, several research studies on the impact of renewable energy technology innovation and financial development on environmental degradation have utilized either a time-series or panel data analysis. Comparatively, very few studies have used a financial development index, technological innovation, or renewable energy investment to determine the impact that these factors have on CO_2 emissions. Therefore, this research fills the gap in the existing research.

DATA AND METHODS

The following section will discuss the variables used in this study, their measurements, and the data sources used. The annual time series data covers CO_2 carbon emissions in KT, the economic complexity index, an aging population, financial development, technological innovations, industrial structure, and investment in renewable energy from 1990 through 2018. In addition, the information, along with its units and sources, can be found in **Table 1**. Moreover, the scatterplot graphs of variables are given in **Figures 1–5**.

Econometric Model

In this study, an attempt is made to investigate the long-run association between the chosen variables. We use carbon emissions as our dependent variable. We use the economic complexity index, population aging, financial development, technological innovations, industrial structure, and investment in renewable energy sources as our explanatory variables. The data transformation into logarithmic form is done because it results in more efficient, better, and more consistent outcomes (Baek, 2015). The logarithmic representation of the data makes it possible to obtain smooth data, but it also solves the problem of heteroskedasticity. The ECI is not converted into log form before

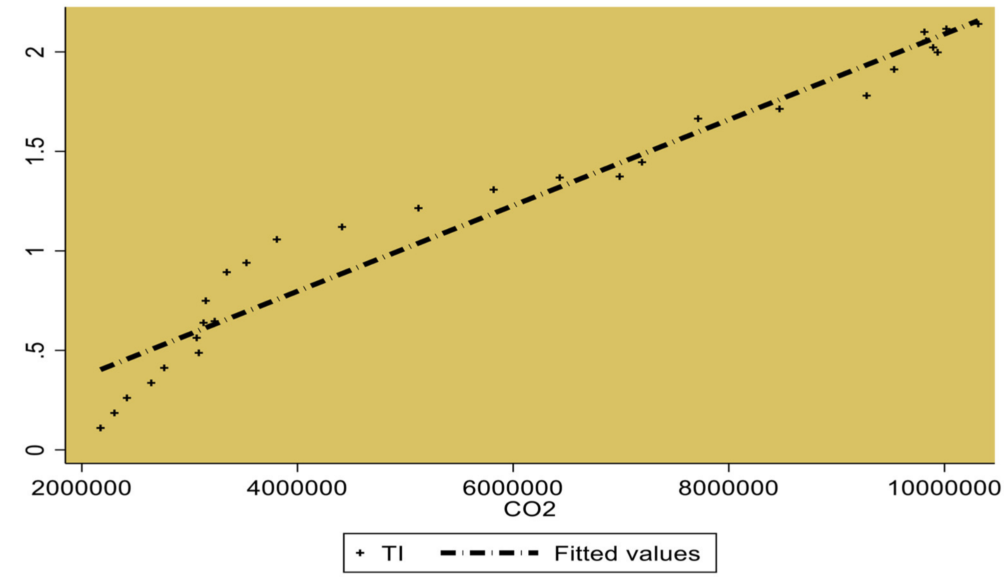

FIGURE 3 | Scatterplots of technological innovation vs. CO_2 emissions.

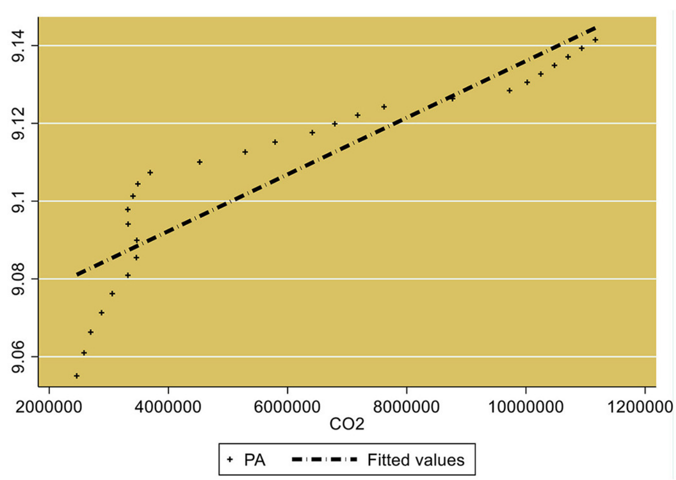

FIGURE 4 | Scatterplots of population vs. CO_2 emissions.

being used as an index. The model is presented in the following.

$$\mathbf{CO_2 = f(ECI^{\beta 1}, PA^{\beta 2}, REI^{\beta 3}, FD^{\beta 4}, TI^{\beta 5}, IS^{\beta 6})} \quad (1)$$

By taking its natural log

$$LCO_{2,t} = \beta_0 + \beta_1 ECI_t + \beta_2 PA_t + \beta_3 REI_t + \beta_4 FD_t + \beta_5 TI_t + \beta_6 IS_t + \mu \quad (2)$$

The letter t denotes the time trend, and the letter denotes the error term. The Economic Complexity Index, or ECI for short, PA stands for "population aging," REI stands for "investment in renewable energy," FD stands for "financial development," TI stands for "technical innovations," and IS refers to "industrial structure." CO_2 denotes emissions of carbon, and B0 is unchanging.

The descriptive statistics regarding the variables are presented in **Table 2**. The following table reports the descriptive statistics, including the mean, median, maximum, and minimum values and the standard deviation and probability values. The average rate of population decline is the highest, while the average rate of carbon emissions is the lowest. The table demonstrates that all of the variables follow a normal distribution.

The summary of the correlation matrix is presented in **Table 3**. The concentration of CO_2 has a positive and significant relationship with ECI. Similarly, population aging, investment

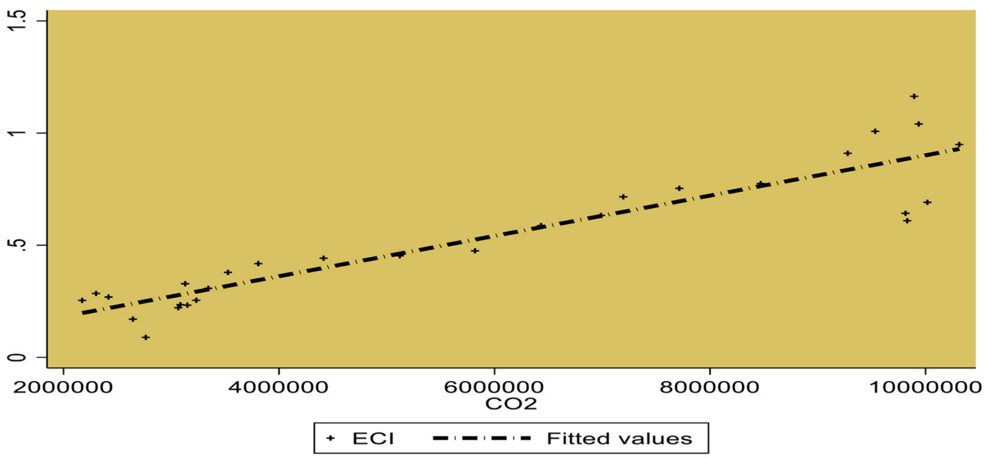

FIGURE 5 | Scatterplots economic complexity index vs. CO_2 emissions.

TABLE 2 | Descriptive statistics.

	LCO_2	ECI	PA	TI	REI	IS	FD
Mean	1.87469	4.96572	11.28974	8.56974	3.96547	6.85469	7.54128
Median	1.61235	3.85412	9.541326	7.96451	2.96471	5.23897	7.23851
Maximum	7.95644	11.8546	21.8546	14.9657	6.98547	12.8745	10.2314
Minimum	0.89524	0.14569	0.89745	0.98451	0.02374	0.75871	0.63984
Std. dev.	0.9820	0.8456	0.4031	0.3478	0.5641	0.8456	0.4145
Prob.	0.0000	0.0001	0.0000	0.0005	0.0000	0.0000	0.0008

in renewable energy, and financial development positively correlate with rising carbon emissions. In addition, technological advancements and industrial structure negatively correlate with the variable that is being explained. As a result, no single variable has a high correlation with the variable that is being explained; consequently, we can say that there is no multicollinearity in our chosen variables. Moreover, **Figure 6** presents the study plan.

Estimation Procedure and ARDL

We use the most advanced method, called Autoregressive Distributed Lag or ARDL bound tests for short. These tests were developed by Pesaran (2015). This method has a number of advantages over other methods, such as the Engle and Granger technique (Citation needed), which is used for two different variables. On the other hand, the Johansen Cointegration (Citation needed) method is utilized for analyses involving more than two variables. Therefore, the Johansen Cointegration model is superior to the Engle and Granger models. Adekoya et al. (2022) developed an extended version of the VAR model. However, for it to be applicable, certain conditions, such as dealing with a large sample size and meeting the pre-conditions for the cointegrated VAR, state that all variables must be integrated in the same order, i.e., I, must be met first (1). The ARDL technique eliminates these problems, but it also has a number of other significant benefits. When dealing with a small sample size, the ARDL cointegration method is preferable to the JJ method. Second, it can be utilized regardless of whether the variables in question are composed entirely of I(0), I(1), or a combination of both I(0) and I(1). Third, it accurately estimates the number of delays in the DGP (Data generating process), especially concerning the transition from the general to the specific process, as Saadaoui (2022) has reported. A straightforward OLS transformation can be used to derive the error correction model from the bound testing method, which brings us to the fourth point. ECM illustrates the mechanism for adjusting from short to long run without compromising the integrity of the long-run data. Fifth, if some endogenous regressors exist, the ARDL approach offers unbiased estimates in the long run. Researchers implement instrumental variables to circumvent the endogeneity problem (s). Nevertheless, there is no such thing as the perfect instrument. Making the model dynamic and introducing the variable (s) lags is the most effective method. The model is made dynamic by using the ARDL approach. Although ARDL can be utilized regardless of whether all variables are stationary at level, i.e., I(0) or I(1), or a mixture of the two (,). However, Ouattara commented that we are unable to use ARDL because the bound testing approach is based on I(0), I(1), or a mixture of these two sets if any of the variables being investigated are stationary at the second difference. As a result, we examine each variable's "unit root" property to ensure that none of the variables should be considered stationary at the second difference. We use ADF (Im et al., 2003) and the Zivot unit root test to accomplish this.

TABLE 3 | Matrix correlation.

	LCO_2	ECI	LPA	LTI	LREI	LIS	LFD
LCO_2	1						
ECI	0.2365	1					
LPA	0.7145	0.2345	1				
LTI	−0.5641	0.6354	−0.6354	1			
LREI	0.6358	0.4123	0.2546	0.6574	1		
LIS	−0.6987	0.3265	−0.7356	0.2385	0.7412	1	
LFD	0.3987	−0.2385	0.5234	−0.4198	0.4187	0.6981	1

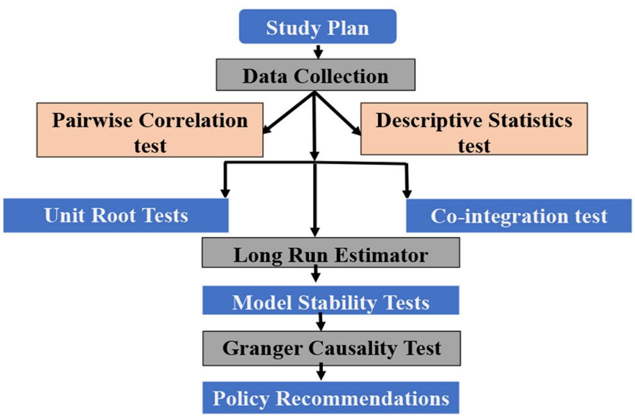

FIGURE 6 | Scheme of study.

The basic idea behind the autoregressive distributed lag to co-integration approach is that it uses two steps to investigate the long-term relationship between the different variables. First, using the F-statistic, one needs to determine whether or not there is a relationship over the long run between the variables. If the F-statistic demonstrates that cointegration does exist, the next step is to investigate the long-run and short-run coefficients. This method is based on the joint F-statistic, and this approach has no co-integration of the null hypothesis. Im et al. (2003) reported two different types of critical values, which they referred to as lower bounds and upper bounds, respectively. In lower bounds, variables are assumed to be I(0), whereas, in upper bounds, they are assumed to be I(1).

Suppose the calculated F-Statistic is greater than the upper bounds. In that case, this indicates that the null hypothesis of no co-integration has been rejected and that the variables do, in fact, exhibit long-run co-integration. If the calculated F-statistic is less than the lower bounds, then we cannot reject the null hypothesis that there is no co-integration, and we are also unable to move forward with the ARDL model. It is inconclusive if the calculated F-statistic falls somewhere in the middle of the lower and upper bounds. In this particular scenario, Peter Boswijk (1994) reported that using an error correction term will effectively determine the variables' long-term relationship with one another. The long-run relationship among the variables can be confirmed because the error correction term is negative and significant. The critical bounds were determined by Pesaran (2004) are applicable to large sample sizes. Therefore, the results they provide may be biased due to the limited size of the sample. In 2008, Breitung and Pesaran (2008) introduced the same tables for small sample sizes that are helpful for thirty to eighty observations. These tables can be found here. Due to the limited size of our data set, we have chosen to adhere to Breitung and Pesaran (2008) tables. The following error correction models need to be estimated in order to use ARDL, and their mathematical representation will be as follows:

$$\begin{aligned}\Delta CO_{2t} &= \beta_0 + \sum_{i=1}^{n1} \beta 1\, \Delta CO_{2t-1} + \sum_{i=1}^{n2} \beta 2\, \Delta ECI_{t-i} \\ &+ \sum_{i=1}^{n3} \beta 3\, \Delta PA_{t-i} + \sum_{i=1}^{n4} \beta 4\, \Delta REI_{t-i} \\ &+ \sum_{i=1}^{n5} \beta 4\, \Delta FD_{t-i} + \sum_{i=1}^{n6} \beta 5\, \Delta TI_{t-i} + \sum_{i=1}^{n7} \beta 6\, \Delta IS_{t-i} \\ &+ \Omega_0 CO_{2t-i} + \Omega_1 ECI_{t-i} + \Omega_2 PA_{t-i} + \Omega_3 REI_{t-i} + \Omega_4\, FD_{t-i} \\ &+ \Omega_5 IS_{t-i} + \Omega_6 TI_{t-I} + \mu_t\end{aligned} \quad (3)$$

$$\begin{aligned}\Delta ECI_t &= \beta_0 + \sum_{i=1}^{n1} \beta 1\, \Delta ECI_{t-i} + \sum_{i=1}^{n2} \beta 2\, \Delta CO_{2t-i} \\ &+ \sum_{i=1}^{n3} \beta 3\, \Delta PA_{t-i} + \sum_{i=1}^{n4} \beta 4\, \Delta REI_{t-i} \\ &+ \sum_{i=1}^{n5} \beta 4\, \Delta FD_{t-i} + \sum_{i=1}^{n6} \beta 5\, \Delta TI_{t-i} + \sum_{i=1}^{n7} \beta 6\, \Delta IS_{t-i} \\ &+ \Omega_0 ECI_{t-i} + \Omega_1 CO_{2t-i} + \Omega_2 PA_{t-i} + \Omega_3 REI_{t-i} + \Omega_4\, FD_{t-i} \\ &+ \Omega_5 IS_{t-i} + \Omega_6 TI_{t-I} + \mu_t\end{aligned} \quad (4)$$

$$\begin{aligned}\Delta PA_t &= \beta_0 + \sum_{i=1}^{n1} \beta 1\, \Delta PA_{t-1} + \sum_{i=1}^{n2} \beta 2\, \Delta ECI_{t-i} \\ &+ \sum_{i=1}^{n3} \beta 3\, \Delta CO_{2t-i} + \sum_{i=1}^{n4} \beta 4\, \Delta REI_{t-i} \\ &+ \sum_{i=1}^{n5} \beta 4\, \Delta FD_{t-i} + \sum_{i=1}^{n6} \beta 5\, \Delta TI_{t-i} + \sum_{i=1}^{n7} \beta 6\, \Delta IS_{t-i} \\ &+ \Omega_0 PA_{t-i} + \Omega_1 ECI_{t-i} + \Omega_2 CO_{2t-i} + \Omega_3 REI_{t-i} + \Omega_4\, FD_{t-i} \\ &+ \Omega_5 IS_{t-i} + \Omega_5 TI_{t-I} + \mu_t\end{aligned} \quad (5)$$

$$\Delta REI_t = \beta_0 + \sum_{i=1}^{n1} \beta 1\, \Delta REI_{t-1} + \sum_{i=1}^{n2} \beta 2\, \Delta ECI_{t-i} + \sum_{i=1}^{n3} \beta 3\, \Delta PA_{t-i} + \sum_{i=1}^{n4} \beta 4\, \Delta CO_{2t-i} + \sum_{i=1}^{n5} \beta 4\, \Delta FD_{t-i} + \sum_{i=1}^{n6} \beta 5\, \Delta TI_{t-i} + \sum_{i=1}^{n7} \beta 6\, \Delta IS_{t-i} + \Omega_0 REI_{t-i} + \Omega_1 ECI_{t-i} + \Omega_2 PA_{t-i} + \Omega_3 CO_{2t-i} + \Omega_4\, FD_{t-i} + \Omega_5 IS_{t-i} + \Omega_6 TI_{t-I} + \mu_t \quad (6)$$

$$\Delta FD_t = \beta_0 + \sum_{i=1}^{n1} \beta 1\, \Delta FD_{t-1} + \sum_{i=1}^{n2} \beta 2\, \Delta ECI_{t-i} + \sum_{i=1}^{n3} \beta 3\, \Delta PA_{t-i} + \sum_{i=1}^{n4} \beta 4\, \Delta REI_{t-i} + \sum_{i=1}^{n5} \beta 4\, \Delta CO_{2t-i} + \sum_{i=1}^{n6} \beta 5\, \Delta TI_{t-i} + \sum_{i=1}^{n7} \beta 6\, \Delta IS_{t-i} + \Omega_0 FD_{t-i} + \Omega_1 ECI_{t-i} + \Omega_2 PA_{t-i} + \Omega_3 REI_{t-i} + \Omega_4\, CO_{2t-i} + \Omega_5 IS_{t-i} + \Omega_6 TI_{t-I} + \mu_t \quad (7)$$

$$\Delta TI_t = \beta_0 + \sum_{i=1}^{n1} \beta 1\, \Delta TI_{t-1} + \sum_{i=1}^{n2} \beta 2\, \Delta ECI_{t-i} + \sum_{i=1}^{n3} \beta 3\, \Delta PA_{t-i} + \sum_{i=1}^{n4} \beta 4\, \Delta REI_{t-i} + \sum_{i=1}^{n5} \beta 4\, \Delta FD_{t-i} + \sum_{i=1}^{n6} \beta 5\, \Delta CO_{2t-i} + \sum_{i=1}^{n7} \beta 6\, \Delta IS_{t-i} + \Omega_0 TI_{t-i} + \Omega_1 ECI_{t-i} + \Omega_2 PA_{t-i} + \Omega_3 REI_{t-i} + \Omega_4\, FD_{t-i} + \Omega_5 IS_{t-i} + \Omega_6 CO_{2t-I} + \mu_t \quad (8)$$

$$\Delta IS_t = \beta_0 + \sum_{i=1}^{n1} \beta 1\, \Delta IS_{t-1} + \sum_{i=1}^{n2} \beta 2\, \Delta ECI_{t-i} + \sum_{i=1}^{n3} \beta 3\, \Delta PA_{t-i} + \sum_{i=1}^{n4} \beta 4\, \Delta REI_{t-i} + \sum_{i=1}^{n5} \beta 4\, \Delta FD_{t-i} + \sum_{i=1}^{n6} \beta 5\, \Delta TI_{t-i} + \sum_{i=1}^{n7} \beta 6\, \Delta CO_{2t-i} + \Omega_0 IS_{t-i} + \Omega_1 ECI_{t-i} + \Omega_2 PA_{t-i} + \Omega_3 REI_{t-i} + \Omega_4\, FD_{t-i} + \Omega_5 CO_{2t-i} + \Omega_6 TI_{t-I} + \mu_t \quad (9)$$

In Equation (3), β0 is constant, β1- β6 are error correction dynamics, Δ is the first difference operator, μt is the white noise error term, and the second part of the equation from δ1 to δ6 characterizes the long-run relationship among the variables in the model. ARDL approach based on Wald F-statistic is applied to check the long-run co-integration among the variables of the concern with the null of no co-integration as H0: **Ω**0 = **Ω**1 = **Ω**2 = **Ω**3 = **Ω**4 = **Ω**5 = **Ω**6 = 0 and alternative as H1: **Ω**0≠ **Ω**1≠ **Ω**2≠ **Ω**3≠ **Ω**4≠ **Ω**5≠ **Ω**6≠ 0.

Short-run coefficients must be found after the long-term correlations between variables and the long-term coefficients of the variables have been established. There will thus be a set of short-term models for the variables:

$$\Delta CO_{2t} = \beta_0 + \sum_{i=1}^{n1} \beta 1\, \Delta CO_{2t-1} + \sum_{i=1}^{n2} \beta 2\, \Delta ECI_{t-i} + \sum_{i=1}^{n3} \beta 3\, \Delta PA_{t-i} + \sum_{i=1}^{n4} \beta 4\, \Delta REI_{t-i} + \sum_{i=1}^{n5} \beta 4\, \Delta FD_{t-i} + \sum_{i=1}^{n6} \beta 5\, \Delta TI_{t-i} + \sum_{i=1}^{n7} \beta 6\, \Delta IS_{t-i} + \eta 1 + \mu_t \quad (10)$$

$$\Delta ECI_t = \beta_0 + \sum_{i=1}^{n1} \beta 1\, \Delta ECI_{t-i} + \sum_{i=1}^{n2} \beta 2\, \Delta CO_{2t-i} + \sum_{i=1}^{n3} \beta 3\, \Delta PA_{t-i} + \sum_{i=1}^{n4} \beta 4\, \Delta REI_{t-i} + \sum_{i=1}^{n5} \beta 4\, \Delta FD_{t-i} + \sum_{i=1}^{n6} \beta 5\, \Delta TI_{t-i} + \sum_{i=1}^{n7} \beta 6\, \Delta IS_{t-i} + \eta 2 + \mu_t \quad (11)$$

$$\Delta PA_t = \beta_0 + \sum_{i=1}^{n1} \beta 1\, \Delta PA_{t-1} + \sum_{i=1}^{n2} \beta 2\, \Delta ECI_{t-i} + \sum_{i=1}^{n3} \beta 3\, \Delta CO_{2t-i} + \sum_{i=1}^{n4} \beta 4\, \Delta REI_{t-i} + \sum_{i=1}^{n5} \beta 4\, \Delta FD_{t-i} + \sum_{i=1}^{n6} \beta 5\, \Delta TI_{t-i} + \sum_{i=1}^{n7} \beta 6\, \Delta IS_{t-i} + \eta 3 + \mu_t \quad (12)$$

$$\Delta REI_t = \beta_0 + \sum_{i=1}^{n1} \beta 1\, \Delta REI_{t-1} + \sum_{i=1}^{n2} \beta 2\, \Delta ECI_{t-i} + \sum_{i=1}^{n3} \beta 3\, \Delta PA_{t-i} + \sum_{i=1}^{n4} \beta 4\, \Delta CO_{2t-i} + \sum_{i=1}^{n5} \beta 4\, \Delta FD_{t-i} + \sum_{i=1}^{n6} \beta 5\, \Delta TI_{t-i} + \sum_{i=1}^{n7} \beta 6\, \Delta IS_{t-i} + \eta 4 \mu_t \quad (13)$$

$$\Delta FD_t = \beta_0 + \sum_{i=1}^{n1} \beta 1\, \Delta FD_{t-1} + \sum_{i=1}^{n2} \beta 2\, \Delta ECI_{t-i} + \sum_{i=1}^{n3} \beta 3\, \Delta PA_{t-i} + \sum_{i=1}^{n4} \beta 4\, \Delta REI_{t-i} + \sum_{i=1}^{n5} \beta 4\, \Delta CO_{2t-i} + \sum_{i=1}^{n6} \beta 5\, \Delta TI_{t-i} + \sum_{i=1}^{n7} \beta 6\, \Delta IS_{t-i} + \eta 5 \mu_t \quad (14)$$

$$\Delta TI_t = \beta_0 + \sum_{i=1}^{n1} \beta 1\, \Delta TI_{t-1} + \sum_{i=1}^{n2} \beta 2\, \Delta ECI_{t-i} + \sum_{i=1}^{n3} \beta 3\, \Delta PA_{t-i} + \sum_{i=1}^{n4} \beta 4\, \Delta REI_{t-i} + \sum_{i=1}^{n5} \beta 4\, \Delta FD_{t-i} + \sum_{i=1}^{n6} \beta 5\, \Delta CO_{2t-i} + \sum_{i=1}^{n7} \beta 6\, \Delta IS_{t-i} + \eta 6 \mu_t \quad (15)$$

$$\Delta IS_t = \beta_0 + \sum_{i=1}^{n1} \beta 1\, \Delta IS_{t-1} + \sum_{i=1}^{n2} \beta 2\, \Delta ECI_{t-i} + \sum_{i=1}^{n3} \beta 3\, \Delta PA_{t-i} + \sum_{i=1}^{n4} \beta 4\, \Delta REI_{t-i} + \sum_{i=1}^{n5} \beta 4\, \Delta FD_{t-i} + \sum_{i=1}^{n6} \beta 5\, \Delta TI_{t-i} + \sum_{i=1}^{n7} \beta 6\, \Delta CO_{2t-i} + \eta 7 + \mu_t \quad (16)$$

The symbol ECT denotes the error correction term in Equation (10). This term is used to determine if there is a disturbance in the system and how much time it will take for the system to return to its equilibrium path in the long run. The error correction term has a coefficient of 1, which is 1. Other equations can be explained in a manner analogous to that described above. Error correction can be explained for other equations following a pattern very similar to this one. The Cumulative

TABLE 4 | Lag selection criteria.

Lag	AIC	SC	HQ
0	4.05896	1.8549	0.8569
1	1.7843	1.4975	1.1178
2	−5.2583*	0.9645	−1.8312
3	−3.2385	−4.8862*	−1.23692*

*The * symbol indicates the 10% significance level.*

TABLE 5 | ARDL bound test.

Significance level	I (0)	I (1)
1%	2.96	4.26
2.5%	2.6	3.84
5%	2.32	3.5
10%	2.06	3.4

Sum (CUSUM) and Cumulative Sum of Squares provided by Sarkodie and Adams (2018) can determine whether or not the coefficients are stable over the short and long term. In addition, the Granger causality was used in this investigation to look into the association between variables and their causes.

RESULTS AND DISCUSSION

Lag Length Selection Criteria

The ARDL method is based on the number of regressions (P + 1) k, where P is the number of maximum lags and K is the variable that displays the number of different factors in each equation. The AIC, the Schwarz information criterion, and the Hannan-Quinn information criterion are the three information criteria that form the foundation of the suitable lag selection procedure. The F-statistic is extremely sensitive to the number of lags present in ARDL. Therefore, to accurately estimate the F-statistic, it is necessary to select appropriate lags, the length of which should be the optimal lag length. Most of the tests, specifically HQ and AIC, are based on our selection for the lag. In addition, Saadaoui (2022) argued that AIC is superior when applied to a small sample size. According to **Table 4**, the findings indicate that the ideal number of lags between events is 2.

After making sure that we have chosen the right lag, we will calculate the F-statistics, which will be reported in **Table 5**. It can be seen that the F-statistic is 10.965, which is greater than the upper bounds at 1, 5, and 10% levels of significance. The independent variables are when carbon emissions are taken as the dependent variable, economic complexity index, population aging, financial development, technical innovations, renewable energy investment, and industrial structure. This is because the F-statistic is greater than the upper bounds at all three significance levels. As a result, we are forced to conclude that there is, in the long run, an association between the variables.

Unit Root Test

The unit root test results are presented in **Table 6**, and the unit root tests ADF and Zivot are utilized in this investigation. This test demonstrates that some variables have cointegration at level, while others have cointegration at the first difference, as indicated by the outcomes of the ADF unit root test. In addition, the structural Zivot unit root test is utilized to investigate the expected breaks in the data provided.

ARDL Long-Run Results

This investigation into the long-run behavior of economic complexity index, population aging, investment in renewable energy consumption, financial development, technical innovation, and industrial structure with carbon emissions uses the Autoregressive Distributive Lag (ARDL) model. The estimated results are presented in the following **Table 7**: Within the context of sustainable development in China, the economic complexity index (ECI) is the factor that is being looked at as the primary factor in carbon emissions. The coefficient value is 0.368, which is positively associated with carbon emissions. Since this factor is positively associated with carbon emissions, a change of one unit in this factor would result in a rise in carbon emissions in China of 0.368%. The practice of shifting economies away from farming and toward more modern production and services directly affects the environment, as it encourages exponential growth in the consumption of fossil fuels and significant CO_2 emissions. Structural change is also known as "economic restructuring". This transition necessitates a higher energy consumption, leading to an increase in CO_2 emissions and the deterioration of the environment. The increased complexity of the exported goods is one factor contributing to the poor air quality and extensive energy consumption. In a similar vein, the process of industrialization and the transformation of the productive system both contribute to an increase in the demand for energy and the amount of carbon emissions. In recent decades, particular modern production methods have been shown to have a significantly more positive impact on the environment than the methods they have replaced. For example, in the agricultural sector, the conventional method of fertilizing on farms, in which animals supplied manure to pollinate the land, has been replaced by organic fertilizers, which have resulted in significant pollution issues due to the contamination of heavy metals as well as elevated radionuclide concentrations. This method of fertilizing was responsible for causing the land to be pollinated by animals. The findings are consistent with those obtained in previously conducted research such as Vujanović et al. (2021). In addition, in contrast to Fatima et al. (2021), who focused their research on European nations, this investigation determined a capacity for mitigating the negative effects of economic complexity on environmental degradation. This evidence is the primary contribution and represents a highly innovative and fresh approach to the existing body of research. The complexity of the economy may help reduce carbon emissions. As a result, policymakers should consider it when designing economic growth at the national and regional levels, as well as energy and environmental regulation. The productive system within the host economy is what is meant

TABLE 6 | Unit root tests.

Variable	ADF			Zivot unit root		
	Level	**1st difference**	**Level**	**Break**	**1st difference**	**Break**
LCO_2	−3.4574*	−7.5685	−3.1189**	1999	−6.1256*	2006
ECI	1.4599	−5.1125*	−5.6895*	2007	−6.4425*	2012
LPA	2.4752	−9.6689*	−4.2285*	2000	−7.5782*	2009
LREI	−3.4234**	−6.7456	−3.6642**	2003	−5.9469*	2010
LFD	−4.5236*	−11.237	−2.8823*	2001	−6.7815*	2008
LTI	2.9645	−6.3674*	−3.1578*	2003	−5.9741*	2009
LIS	−3.8564*	−8.2369	−4.9654**	1995	−7.6985*	2004

*The ** symbol indicates the 1% significance level.*

when we talk about a country's economic complexity. Because of this, it has particular effects on the surrounding environment. It is possible to reduce the amount of carbon dioxide released into the atmosphere by properly managing the productive system using mixed baskets and technological innovation. This discovery about the complexity of the economic system is both specific and reassuring.

Similarly, the elderly population is a significant indicator of the continued viability of the environment. The positive association between population aging and carbon emissions is demonstrated by the coefficient value that has been given. This suggests that a 1% increase in the proportion of older people in the population would result in a 0.6514% increase in emissions, respectively. There is a positive correlation between China's carbon emissions and the country's aging population. Adedoyin et al. (2021), Jabeen et al. (2021), and Ziaei (2022) found positive correlations between the percentage of senior citizens and the amount of carbon emissions. This finding is in line with those findings. Our viewpoint is that China's aging population's way of life is distinctive compared to that of people in other countries, particularly western nations. The elderly tend to live a more frugal lifestyle, opting to move in with their children more frequently and taking fewer vacations. According to Mehmood (2021), seniority has a beneficial effect on energy-saving behavior. On the other hand, the effect of population aging on carbon emissions is relatively insignificant (Mehmood, 2021). The following list of reasons explains why China's aging population currently correlates positively with the country's total carbon emissions. The constant availability of new workers is the primary explanation. Compared to developed nations, China's aging population has only been a reality for a relatively short time (China entered an aging society stage in 2001). The current aging of the population, caused by falling fertility rates and rising life expectancy rates, has not resulted in a relative decrease in the size of the labor force. The percentage of the working-age population is growing in most provinces and at the national level overall. During the sample period of our study, China's demographic gap was still present. The consistent availability of work contributed to the expansion of the economy and increased the amount of carbon emissions. Rising labor supplies are the primary cause of increased carbon emissions in countries that are still economically developing. There is a significant positive correlation between China's aging population and the country's total carbon emissions, primarily attributable to the continuously rising labor force. The second cause is connected to psychological aspects and considerations. Like the aging populations in other countries, the aging population in China is becoming less willing to pay for environmental protection. Others also spotted this pattern (Zaman et al., 2021). As people get older, their willingness to pay for improved environmental quality drops significantly (Saraswat and Digalwar, 2021; Wang et al., 2021). Only one-third of people over the age of 65 would be willing to pay higher gasoline prices to protect the environment compared to those aged 15–24. This indicates that older people are less concerned about the environment than younger people (Qashou et al., 2022). Improving the quality of the environment is a process that takes a relatively long time. It is more likely to improve the standard of living of the population in the future.

TABLE 7 | Short run and long run ARDL test.

Variable	Coefficient	Std. error	T-statistics	*P*-value
ECI	0.36851	0.00256	143.94	0.005
PA	0.65142	0.11364	5.7323	0.000
REI	−0.85243	0.21547	−3.9561	0.000
FD	0.96425	0.07896	12.211	0.001
TI	−0.32987	0.12354	−2.6701	0.000
IS	−0.69451	0.13851	−5.0141	0.005
C	−1.23654	0.89254	−1.3854	0.000
Short run ARDL outcomes				
D (ECI)	0.06982	0.00118	59.169	0.0421
D (PA)	−0.23845	0.01123	−21.225	0.000
D (REI)	0.45128	0.123691	3.6484	0.005
D [LREI (−1)]	0.08512	0.004165	20.436	0.047
D (FD)	0.41235	0.12487	3.3022	0.000
D (TI)	1.23654	0.98245	1.2586	0.145
D [TI (−1)]	−0.65234	0.23854	2.7347	0.002
D (IS)	0.02396	0.00012	199.66	0.000
CoinEq (−1)	−0.67452	0.23171	−2.9110	0.002

Source: Author calculation using EViews 10.

More interestingly, the connection between investments in renewable energy and carbon emissions shows an inverse

TABLE 8 | Model stability tests.

Test	F-statistics	*P*-value
Serial correlation test	5.235	0.214
ARCH test	0.9856	0.623
WHITE test	3.1258	0.111
RAMSAY test	1.8521	0.198

association. A 1% increase in this factor would lead to a 0.852% decrease in environmental deterioration, according to the ARDL estimator. This result can be understood by applying some economic logic to the situation. The implementation of policies for REI will encourage investors to invest more in production that uses renewable energy, which will reflect favorably on the environment's sustainability. This result demonstrates that the company has the potential to increase its profitability by increasing the amount of money it invests in the production of electricity using renewable energy. This finding implies that the government can use REI as an effective mechanism to encourage producers to invest in renewable energy production to replace the production of conventional power. It will produce the least overall carbon emissions from green energy consumption because it must cover both electricity generation costs and carbon dioxide emissions from using conventional energy. Because of this, firms are less likely to use conventional energy, resulting in lower overall carbon dioxide emissions. On the other hand, businesses can invest the most heavily in renewable energy because they can set a low price for electricity to stimulate more demand in the market. It then needs to invest more money in renewable energy sources in order to meet the electricity demand.

In a similar vein, it is believed that the estimated coefficient of financial development has a positive association with carbon emissions. The findings indicate that an increase in this factor by 1% would lead to an increase in environmental damage of 0.964%, respectively. This result can be rationalized in some way. The fact that this variable has a positive coefficient indicates that the financial sectors in China do not allow financial resources for environmental protection and do not support organizations or production units that do not use green technologies. According to Wang et al. (2021), liberalization and financial openness are two factors that encourage research and development projects and international investment. The resulting financial obligations and expenditures are the primary sources of technologies that increase energy-related effectiveness and play an essential role in reducing carbon emissions. Financial resources in an economy are a leading factor in channeling resources to areas where productivity is high, and the nation wishes to promote strategically. This is the role that financial resources play in an economy. In addition, in terms of production factors, financial resources are still relatively scarce in China, whereas labor supply continues to outweigh the demand. According to this point of view, the circulation of financial resources plays a primary part in the circulation of other production factors. The flow of labor is contingent upon the geographic region, the industry, or the investment projects that receive financial resources. Therefore, the destination of the flow of financial resources and the direction in which they are channeled plays an extremely significant role, one that is significantly more significant than the role played by any of the other factors, in the process of optimizing economic structure, economic growth, and carbon emissions. Similarly, in the same vein, financial development is not useful for improving environmental quality in countries where the financial sector is still in its early stages. For instance, Huang et al. (2022) argued such for BRICS, Abbas et al. (2022) for Pakistan, and Yumei et al. (2021) argued in the case of developing regions of China. All of these studies were conducted in Pakistan.

Regarding the coefficient of technological innovations, there is an inverse relationship between the two variables (carbon emissions). It can be deduced from this that a 1% increase in this factor would result in a 0.329% decrease in China's total emissions. This finding indicates that R&D has an inverse relationship with carbon emissions, suggesting that higher authorities in China are increasingly interested in R&D projects that aim to reduce CO_2 emissions. Research and development can create novel knowledge, processes, and products thanks to technological advances. According to Feng et al. (2022), the proliferation of innovative technologies can help reduce harmful effects on the environment due to energy consumption usage by improving energy efficiency. This can be accomplished by improving energy utilization. This result is consistent with the findings found in the research of Zhang et al. (2022). It was established that investments in research and development have the potential to stimulate improvements in energy efficiency. According to Zhang et al. (2022), reputable institutions can better direct their efforts toward reducing carbon emissions and, as a result, improve the overall quality of the environment while fostering economic growth. Therefore, in this case, the negative nexus demonstrates the successful implementation of environmentally friendly policies by India's institutions and the government to enhance energy usage efficiency.

There is a possibility that the industrial structure is responsible for a significant portion of the environmental damage. According to the outcomes that have been estimated, this means that an increase in the industrial structure of 1% would result in a decrease in emissions level of 0.329%. This result is not only very interesting but also makes some sense. Developing a more efficient industrial structure is inextricably bound up with economic and demographic factors. Because of this, it is to be anticipated that urban development has resulted in a continuous increase in industrial solid waste despite a relatively slow garbage disposal capacity that lags behind the production of solid waste, which has resulted in a phenomenon known as a "garbage siege" (Anser et al., 2020). As a result of the fact that industrialization is the primary driver of both urbanization and economic development, more pollution is produced during such development processes. As a result of China's relatively high levels of urbanization and the country's relatively low proportion of traditional industries, China's urbanization processes have resulted in less pollution being released into the environment. Even though urbanization has contributed to increased environmental pollution in China, this problem has become less severe as the percentage of the tertiary industry

TABLE 9 | Granger causality tests.

DV	Type of Granger causality							
	Short run (lag)						Long run	
	ΔLCO2	ΔECI	ΔLPA	ΔLREI	ΔLFD	ΔLTI	ΔLIS	ECT-1
	F-statistics (*P*-values)							*t*-stat
ΔLCO2	–	1.0478 (0.111)	1.6387 (0.339)	1.24781 (0.005)	2.23458 (0.081)	1.96542 (0.331)	2.41237 (0.852)	−3.3741 (−1.3856)
ΔECI	3.47124 (0.000)	–	1.46871 (0.623)	1.42603 (0.5611)	3.2358 (0.000)	3.6541 (0.000)	5.23659 (0.000)	−1.35468 (−0.5689)
ΔLPA	4.1456 (0.000)	1.45127 (0.125)	–	1.13589 (0.853)	5.91856 (0.000)	1.85461 (0.555)	3.14561 (0.096)	2.52134 (1.1245)
ΔLREI	1.4451 (0.191)	2.5689 (0.212)	1.85121 (0.213)	–	3.98745 (0.005)	1.2345 (0.999)	1.98651 (0.962)	0.65480 (0.9645)
ΔLFD	5.8546 (0.000)	1.8952 (0.121)	4.8546 (0.005)	1.68452 (0.522)	–	1.4456 (0.287)	2.12489 (0.471)	−0.86944 (−1.2341)
ΔLTI	1.6314 (0.962)	2.1245 (0.113)	1.63214 (0.087)	2.8541 (0.418)	1.5236 (0.851)	–	3.96894 (0.005)	−1.56891 (−0.6312)
ΔLIS	1.6396 (0.895)	1.5692 (0.235)	3.6245 (0.412)	2.652 (0.285)	5.3245 (0.000)	7.9852 (0.002)		0.96325 (0.0125)

has grown. This may be because of the following reasons: First, as a result of ongoing urbanization, advances in technology, and modifications to industrial policies, the percentage of the economy comprised of the tertiary industry has been steadily growing over the past few decades. An improvement in the industrial structure can also result in decreased reliance on resources and energy in the production processes of businesses, which directly impacts the ecological environment (Waqas, 2021). Second, due to the optimization and upgrading of industrial structure, the percentage of traditional industries with high energy consumption levels, pollution, and emissions has been gradually decreasing. At the same time, resources have been shifted from industries with low utilization efficiency to industries with high efficiency and low levels of pollution. As a result, significant progress has been made in reducing pollutant emissions and enhancing the ecological environment.

Stability Tests

Because there is an association in the long run between the chosen variables, it is now essential to test the robustness of the model. As a result, the various tests are utilized in this study to investigate the serial, correlations, autocorrelation, and other such phenomena. The results of each test are detailed in **Table 8** below.

After the stability test and long-run outcomes, there is a need to check out causal association among variables. Therefore, this study uses the Granger causality test to investigate the causal effect of one variable on another variable. The results of causality analysis are given in **Table 9**. The given results found a bi-directional causality between population aging and financial development, which infers that any change in population aging would change the activities of financial institutions and vice versa. It will be meaningful if we say the policies concerning population aging and financial development are working together. Moreover, a two-way causal association was found between industrial structure and technical innovations. This infers that as research development expenditures increase, the industrial structure becomes more developed due to advanced technologies. Similarly, this behavior of the industrial structure can be judged for technical innovations. On the other hand, there was a uni-directional association between environmental degradation and investment in renewable energy, while there has been no evidence for feedback. Likewise, the economic complexity index granger causes environmental quality, financial development, technical innovations, and industrial structure. Moreover, population aging found a one-way causal association between population aging and environmental degradation in China's economy. Likewise, renewable energy investment also causes financial development, and no feedback exists. In the last, the industrial sector granger causes financial development.

CONCLUSIONS AND POLICY RECOMMENDATIONS

This study aims to investigate the impact of technological advancements and industrial structure changes on carbon emissions from 1990 to 2018. We research the socioeconomic indicators of China's economy to understand its potential for sustainable development. These determinants have surprising results, and the factors in question are the economic complexity index, the aging population, investments in renewable energy, and the growth of the financial sector. The application of the ARDL bound test allowed for the discovery of these results. Based on this analysis, the following generalizations can be made: Due to an increase in the economic complexity index, China's overall carbon emissions have been climbing steadily from 1990 to 2018. In addition, an aging population and the growth of the financial sector both contribute to an increase in emissions and a decline in the quality of the environment. In a similar vein, the industrial structure, investments in renewable energy, and industrial structure all contributed significantly to the overall quality of the environment. Additionally, the Granger causality test was utilized in this research to investigate the causal association between variables. The results revealed a two-way causal linkage between population aging, financial development, technical innovation, and industrial structure.

Policy Recommendation

In light of the anticipated findings, this research offers recommendations for environmental policy to create a sustainable environment. It is imperative that China put into action strategies that will halt the rise in CO_2 emissions—owing to the fact that the economic complexity of the chosen economy is organized in a fashion that promotes the emission of greenhouse gases. The transition in the economy demonstrates a shift from an "energy-intensive economy" to a "technology-intensive economy." In order to reduce the amount of CO_2 emissions in China, structural improvements in the environment may be required. Because an aging population does not significantly contribute to maintaining a sustainable environment, it is essential to reevaluate the policies in question. First, China's population aging (PA) has resulted in the consumption of significant energy resources and has caused significant damage to the natural environment.

Consequently, China's current energy consumption structure needs to be revised to reduce the country's levels of air pollution and increase the effectiveness of energy consumption (Mngumi et al., 2022). To accomplish this goal, the government and businesses will need to collaborate. It is the government's responsibility to develop appropriate policies that will not only direct the implementation of consumption structure upgrades in energy-intensive industries but will also encourage the use of clean energy across the entire country. In the process of developing policies to protect the environment, it is essential to take into account regional variations, such as increasing rates of seniority and the proportion of people employed in service industries (Chien et al., 2021; Hai Ming et al., 2022; Mngumi et al., 2022; Nasir et al., 2022). As a direct result of this, China is in a position to impose stricter environmental regulations and higher business entry barriers.

Undoubtedly, China's rapid economic development significantly contributes to the country's environmental damage. As a result, economic development and financial activities should be centered on enhancing the quality of the environment, and the promotion of forms of financialization that are more environmentally friendly should be a priority. Public and macroeconomic policy development should center on environmentally friendly and sustainable forms of finance. It should be discouraged to allocate financial resources to industries with lower environmental impact efficiency. At the same time, resources should be allocated to industries that positively impact the environment.

Similarly, technological innovations (TI) significantly contribute to environmentally sustainable practices. Based on our empirical research findings on the costs of TI, we have concluded that TI is good for the natural environment. Because the statistics demonstrated very strong and empirically robust results, we can infer with high levels of confidence that TI is essential to the process of addressing environmental challenges. Because of this, it is necessary to direct both public policy and the distribution of resources toward research and development when formulating policies, particularly when attempting to reduce carbon emissions. This will make it easier for us to accomplish our goal of reducing carbon emissions to zero. In addition, it has been suggested that to maintain the structure of the industrial system. Advanced industries need to adjust their development patterns to become green. For a very long time, China's industrialization has been defined by low output, high input, low efficiency, and high consumption. Even after several years of economic development, a significant portion of China's economy comprises secondary industries in many regions. Therefore, a significant step is optimizing inventory stocks and controlling increments at the beginning of transitioning from the nation's traditional model of high energy consumption, high input, and extensive industrial development to one that promotes the development of the green industry. This transition could initially involve optimizing inventory stocks. This supposedly "optimized" inventory will allow China to optimize the production of its already-established industrial enterprises, continuously promote and implement a wide range of innovative technologies and pieces of equipment, and eventually realize the intensive, environmentally responsible development of its industrial enterprises.

Future Research Directions and Limitations

Even though the current research makes it possible to determine solid findings, additional research needs to be conducted using a variety of factors that influence environmental sustainability. These factors include urbanization, trade, foreign direct investment (FDI), globalization, industrialization, population, and so on. In addition to that, this research employed the use of CO_2 as a stand-in for environmental deterioration. Therefore, subsequent research ought to make use of various stand-ins for environmental deterioration.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Does the digital economy promote "innovation and entrepreneurship" in rural tourism in China?

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This paper focuses on the impact of the "Digital Economy" on rural entrepreneurship. Unlike previous literature, the perspective of this paper focuses on a specific industry—tourism—and identifies a new mediating mechanism by which the "Digital Economy" affects rural tourism entrepreneurship—the promotion of innovation. The paper further clarifies the fact that the "Rural Digital Economy Index," which is a dimension of the Digital Economy Indicator System, is the key to the mechanism of action. Theoretically, first, through a literature review, this paper provides a rationale for the "Digital Economy" to promote innovation behavior by reducing the cost of innovation. Second, using a product matching model, this paper argues that a rural tourism market characterized by innovation can stimulate more entrepreneurship. Empirically, using a sample of 150 counties in the Yangtze River Delta region of China, this paper argues that the higher the digitalization index of a county's rural economy, the more national model villages and towns this county has (all of which include product innovation in the selection criteria) and more tourism entrepreneurial activities. Econometric methods such as endogeneity, spatial econometric regression, and sensitivity analysis proved the findings robust. Our recommendation is that the Chinese government could focus on improving the innovation environment for rural residents in the future, so that entrepreneurial activities will be spontaneously stimulated by market mechanisms.

KEYWORDS

entrepreneurship, digital economy, product innovation, rural, tourism

Introduction

The Chinese government has proposed to develop "Digital Economy" in rural areas during the 14th Five-Year Plan (2021–2025). Conceptually, the "Digital Economy" has a broader connotation than "Digital Technology." Developing "Digital Technology" refers to the Chinese government's provision of Internet, mobile Internet, e-commerce and other infrastructure as well as online trading platforms in rural areas. Developing

"Digital Economy" means that based on the development of digital infrastructure construction (measured by the "Digital Infrastructure Index"), the Chinese government promotes the integration of data elements into rural production processes (measured by the "Rural Economy Digitalization Index"), the digital products and services into farmers' lives, and the digital thinking into rural government services (measured by the "Rural Governance Digital Index"), so as to provide digital impetus to achieve the comprehensive revitalization of rural areas. On the other hand, as an important solution to the problem of rural poverty, "mass entrepreneurship and innovation" is a long-term national policy of the Chinese government to promote rural-economic vitality. Entrepreneurship can increase the income of rural entrepreneurs, create more jobs in rural communities, and increase the economic growth rate in lagging rural areas (Stephens et al., 2013; Blattman et al., 2014; Dong et al., 2021). Therefore, this paper focuses on whether the digital economy helps to stimulate entrepreneurial activities in rural China. Further, this paper attempts to answer which specific Indicator of the "Digital Economy" (Digital Infrastructure Index, "Rural Economy Digitalization Index" or "Rural Governance Digitalization Index") is more conducive to stimulating entrepreneurship and how to stimulate entrepreneurship, with the aim of improving the science and effectiveness of the government's future supporting policies.

Many scholars have focused on the relationship between the "Digital Economy" (or rather, "Digital Technology") and entrepreneurship. Cumming and Johan (2010) suggest that the Internet leads to a clustering of rural entrepreneurial activity. Beck et al. (2018) discusses the impact of the mobile Internet on entrepreneurship, an article unique in that it is calibrated using a general equilibrium model. Barba-Sánchez et al. (2021) concluded that the information technology capabilities of entrepreneurs have a positive relationship with entrepreneurship. Deller et al. (2022) studied the impact of broadband speed on local new venture creation, this article specifically divided broadband speed into several dimensions and found the indicators that most affect entrepreneurial outcomes, this line of research provides insights for our study. Tan and Li (2022) proposed that Internet technology has a greater effect on promoting entrepreneurship in rural areas of China than in cities, and the mechanism of action is to improve rural entrepreneurs' access to information and financing. Wang et al. (2019) proposed another mechanism by which the Internet influences rural entrepreneurial activity—social networks. Barnett et al. (2019) explored that the popularity of smartphones affects rural entrepreneurial activity and the mechanisms of action are information accessibility and social networks. Bogoviz et al. (2017) argues that there are several factors that moderate the impact of digital technology on entrepreneurial activity.

In summary, the academic progress in this field exhibits the following characteristics: (1) Regarding the object of research, attention has been paid both to the impact of technology itself and of different dimensions of technology. (2) Regarding the research methodology, some scholars have started to use general equilibrium analysis of economics as a research paradigm. (3) Regarding the research focus, scholars have increasingly focused on the mechanisms of the Digital Economy 's effect on entrepreneurial activity.

Unlike these literatures, the marginal contributions and innovations of this paper are as follows: First, this paper focuses on entrepreneurial activity in one specific sector in rural China—tourism, which accounts for one-third of all tourism revenue in China and is one of the most important industries in rural areas. Limiting the relationship between the "Digital Economy" and entrepreneurship to one industry specifically helps us to identify new mechanisms of action, namely, the "Digital Economy" promotes innovation in rural tourism products, and a tourism market characterized by innovation in turn promotes more entrepreneurial activity.

Second, this paper explicitly uses "Digital Economy" as an explanatory variable, which, as mentioned earlier, is much more encompassing. The data is derived from an official survey conducted by Peking University, and it contains 4 primary indicator, 13 secondary indicators, and 39 tertiary indicators, based on county-level administrative districts (administrative districts below the urban level and dominated by the township economy). Based on the needs of the study, this paper uses 3 of 4 first-level indicators (shown in Table 1), which portray a county's investment in digital infrastructure, a county operator's understanding and use of digital technology, and a county's level of digital governance, respectively. We focus on which of these indicators can work through intermediary mechanisms.

TABLE 1 Dimensions of the digital economy.

	Primary	Descriptions
Digital Economy	Digital Infrastructure Index("DII" in short)	Level of government investment in Internet, mobile Internet, big data platforms, Internet of things, and other related facilities.
	Rural Economy Digitalization Index ("REDI" in short)	Entrepreneurs' understanding of digital technology; entrepreneurs' use of data in production and marketing; digital transformation of industry chain business models.
	Rural Governance Digital Index ("RGDI" in short)	Government use of digital technology in service delivery; government use of digital technology in managing markets

Finally, based on the clear market scope, this paper uses the general equilibrium analysis of neoclassical economics as a research paradigm to provide explicit mathematical expressions for the causal relationship between the "Digital Economy" and entrepreneurship.

The subsequent content is organized as follows: The second part is the theoretical analysis, which consists of two subsections. The first subsection gives the theoretical basis for the "Digital Economy" to promote product innovation in rural tourism by means of a literature review. The second subsection uses the product matching model from industrial organization theory to argue that a rural tourism market characterized by differentiated innovation stimulates more entrepreneurial activities.

The third section is an empirical analysis that uses an econometric model to test the relationship between the "Digital Economy" and product innovation, as well as the "Digital Economy" and entrepreneurial activities, respectively. Among them, regarding product innovation, this paper creatively uses the proxy variable measure. This chapter includes four subsections. First, we introduce the sample of the study, the values of the explanatory and explanatory variables, and the descriptive statistics of the sample. Second, we present the econometric model and analyzes the computational results. Third, we discuss the endogeneity problem of the explanatory variables and gives solutions. At last, we discuss a series of robustness issues.

The fourth section concludes the study. First, we give the most central conclusion of the paper. Second, we make policy recommendations based on the conclusions. Finally, we illustrate where the paper can be improved and where future research can be directed.

Theoretical analysis

Why do people choose to start a business in a specific industry (tourism) in a specific geographic area (rural)? According to microeconomics, an important pull factor is the ability of the industry to provide entrepreneurs with a higher return on investment, or excess profits (Falco and Haywood, 2016). When tourist preferences are heterogeneous and monopoly profits come from operators offering differentiated products through innovation, monopoly profits will further encourage more rural residents to enter tourism through entrepreneurship, when the market is characterized by product differentiation. However, rural tourism in China has been characterized by product homogeneity for a long time, which has led to two scenarios: on the one hand, Chinese tourists' preferences are not met and the consumer market is not made bigger and stronger; on the other hand, price competition among operators is exceptionally stimulating and operating profits are meager. As a result, product homogeneity has reduced the dynamics of the rural tourism market and constrained more entrepreneurial behavior.

Digital economy and rural tourism product innovation

One of the reasons for the homogenization of rural tourism in China: The cost of innovation

Scholars such as Xu et al. (2013), Ding and Ma (2018), and Xu et al. (2021) have successively explored the phenomenon of homogenization of rural tourism in China and its causes. In addition, a large number of studies published in Chinese domestic academic journals also provide explanations for the homogenization phenomenon, which, in summary, include the following: (1) Lack of information channels makes it difficult for rural tourism entrepreneurs to access the consumption preferences of urban tourists. (2) Lack of risk protection mechanisms, and the inability of financial institutions to access entrepreneurs' credit information and their reluctance to provide financial support. (3) Lack of coordination mechanism; tourism behavior contains multiple links, and product innovation in a single link is difficult to obtain cooperation from other links in the industry chain. (4) The Chinese government's habit of setting entrepreneurial role models indirectly leads to product homogenization. Solving the above problems requires a new market environment and institutional environment, which is unlikely to be changed by entrepreneurs alone. When the cost of innovation in a given environment is high, entrepreneurs are reluctant to innovate according to Arrow's (1962) model of innovation incentives.

The emergence of the "digital economy": Reducing the cost of innovation

From the development practice, it is clear that the "Digital Economy" as a new economic form effectively solves the above mentioned factors that lead to product homogenization, and thus reduces the cost of innovation. Taking the practice in China as an example. For factor (1), the combination of the Internet and technologies such as big data and cloud computing can achieve an accurate portrait of both supply and demand, solve the problem of asymmetric market information, and increase the probability of successful innovation. For factor (2), digital finance meets the financial needs of rural industries, solves the problems of financing difficulties and high financing costs for rural entrepreneurs, and reduces the innovation risks of entrepreneurs. For factor (3), the "Digital Economy" has given rise to the platform economy, a new business model (Spulber, 2019), which promotes entrepreneurs located in different parts of the industry chain to cooperate under a unified rule and framework and encourages collaborative innovation. For factor (4), the "Digital Economy" improves the government's governance capacity and governance efficiency, strengthens the consultation and interaction between policymakers and stakeholders, and improves the monitoring mechanism so that innovative behavior is protected.

Many academic results provide a theoretical basis for the inference that the "Digital Economy" can reduce the cost of innovation. Asghari and Gedeon (2010) proposed that information technology reduces the transaction and administrative costs of firms and enhances customer communication. Goldfarb and Tucker (2019) argue that digital technologies such as the Internet can reduce costs in five areas, including search costs, replication costs, transportation costs, tracking costs, and verification costs. Among them, reducing search costs can improve the efficiency of information communication and organization; reducing replication costs can help companies to innovate in new product development. Bhimani et al. (2019) proposed that social media reduces knowledge flow costs and knowledge management costs and drives customer-centric innovation behavior. Urbinati et al. (2020) similarly suggested that digital technologies can reduce the cost of managing knowledge and help firms develop and nurture open innovation. Moreover, since the key to successful innovation is managing information and knowledge (Barba-Sánchez et al., 2018), which is carried in data, digitally driven innovation (DDI) becomes a new innovation strategy (Saura et al., 2021).

Evidence on innovation costs and innovation behavior

Moser (2005) analyzes the impact of patent law on innovation and suggests that innovation only occurs when profits can be expected. Simons and Astebro (2010) argue that whether inventors commercialize their inventions depends on profits. Although these two papers do not explicitly present costs, costs are internalized in profits since profits are composed of benefits and costs. Another related paper comes from Cucculelli and Ermini (2013), where the authors suggest that entrepreneurs willing to innovate a product need to be risk-averse due to the presence of innovation costs that lead to uncertainty of returns.

Innovation promotes entrepreneurship

We use the general equilibrium research paradigm of economics to argue for the relationship between rural tourism innovation and rural tourism entrepreneurship. First, we construct a virtual tourism market in a rural area and make the following assumptions: (1) the number of tourists is N and has heterogeneous preferences; (2) the number of entrepreneurs already in the market is M . Entrepreneurs seek to maximize profits and, influenced by the "Digital Economy" mentioned above, each entrepreneur is willing to offer one (and only one) differentiated product through innovation.

Second, we use a product matching model to describe the relationship between supply and consumption in the market. The product matching model is derived from Hotelling's one-dimensional linear model, in which N tourists are uniformly distributed in a one-dimensional space and each tourist occupies a specific location $\overline{r}_i$, and the model uses different locations to denote different preferences. M entrepreneurs are also uniformly distributed in a one-dimensional space (which can also be expressed as M products uniformly distributed in a one-dimensional space), and each entrepreneur (hereafter uniformly "each product") occupies a specific position r_i , and the model uses different positions to represent different product characteristics.

When $\overline{r}_i = r_i$, the visitor's preference matches exactly with the characteristics of product i , and the visitor will receive 100% of the value return by paying the price of p_i . When $\overline{r}_i \neq r_i$, the visitor's preference does not match the characteristics of product i , and the visitor will receive less than 100% of the value return by paying a price of p_i . Here a utility conversion is performed where we convert spending p_i to receive a value return less than 100% to spending more than p_i to receive a value return equal to 100%; the conversion does not change the visitor utility. The basis for such a conversion is that a product cannot be completely inconsistent with tourists' preferences, and in the total payment, we regard the payment that meets preferences as normal goods and the payment that does not meet preferences as aversive goods, then the slope of the utility curve is positive and the utility at low payments can be equal to the utility at high payments. At this point, the utility of visitors at each position in the model is the same, and the consumption decision depends on the price paid, which can be represented by a mathematical formula. We give a more detailed explanation in graphical form in Figure 1. Consumers who do not match the product characteristics pay an additional price of $\sigma\left|\overline{r}_i - r_i\right|^2$ and receive 100% value in return. The consumer will choose the one with the minimum price paid between the two nearest products.

There is a position between two tourism products adjacent to each other in the model, and this position is the demarcation point of the market range of the two products. Because the model is one-dimensional, product i has a demarcation point in each of the left and right directions, respectively, and the range between the demarcation points is the market range of product i. We denote the demarcation point and the market range by $\left[\overline{r}_i, \overline{r}_{i+1}\right]$. At the demarcation point, tourists consume the nearest product on the left side with equal payment to consume the nearest product on the right side, and for tourists, there is no difference between the two products. At the other locations, only one product pays the minimum price and is chosen by the tourist. Therefore, there exists

$$\overline{r}_i = \frac{p_i - p_{i-1} + \sigma\left(r_i^2 - r_{i-1}^2\right)}{2\sigma\left(r_i - r_{i-1}\right)} \quad (1)$$

$$\overline{r}_{i+1} = \frac{p_{i+1} - p_i + \sigma\left(r_{i+1}^2 - r_i^2\right)}{2\sigma\left(r_{i+1} - r_i\right)} \quad (2)$$

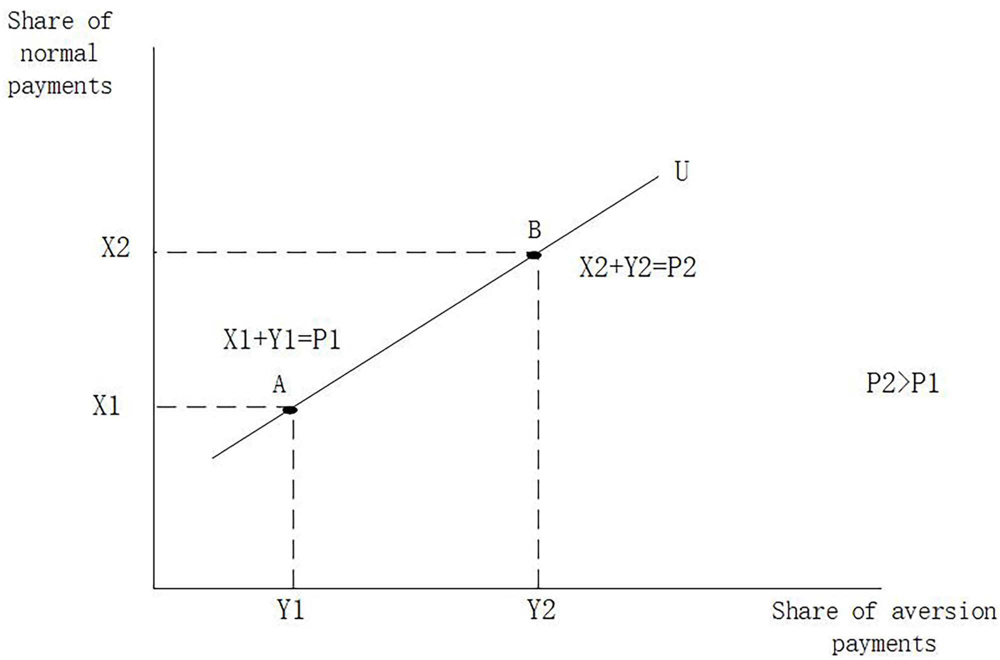

FIGURE 1
Note: In the above figure, *P*1 at point A corresponds to the actual price paid by the tourist, but due to the incomplete match between the tourist product characteristics and the tourist preferences, only the amount paid for *X*1 brings value return, while the amount paid for *Y*1 brings a non-positive value return. If tourists' preferences and tourism product characteristics match perfectly, at point A, the expenditure of *P*1 should be fully compensated by the value return of *X*2, but there is a deviation, and the price of *P*2 must be paid to obtain the value return of *X*2, which means more payments that cannot obtain the value return. If the consumer makes a choice based on utility, *A* and *B* are equivalent, so we convert the consumer's utility at point *A* to the utility at point *B*.

Under the assumption that each entrepreneur (or each product) seeks to maximize profit, the profit equation can be expressed as

$$\pi_i = \int_{\bar{r}_i}^{\bar{r}_{i+1}} N\left(p_i - c\right) dr = N\left(p_i - c\right)\left(\bar{r}_{i+1} - \bar{r}_i\right) \quad (3)$$

The *c* in the above equation represents the marginal cost of 1 unit of rural tourism product. We proceed to calculate the first-order partial derivative of π_i with respect to p_i. Substitute Eqs. (1) and (2) into Eq. (3), we have

$$p^*\left(M\right) = c + \frac{\sigma}{M^2} \quad (4)$$

Equation (4) shows that entrepreneurs price tourism products above the marginal cost of tourism products, which indicates that product innovation brings market power to entrepreneurs, and entrepreneurs can thus earn excess profits (or monopoly profits). The excess profit attracts more entrepreneurs to enter the tourism market, and new entrants also need to pay the innovation cost of $F\left(\theta\right)$, where θ is a measure of the level of development of the "Digital Economy" and $F'\left(\theta\right) < 0$. Therefore, the number of entrepreneurs in the tourism market at equilibrium can be expressed as [substituting equation (4) and F into Eq. (3)]

$$M^* = \sqrt[3]{\frac{\sigma N}{F\left(\theta\right)}} \quad (5)$$

We can find that when the market reaches equilibrium, the number of entrepreneurship in the market is proportional to the number of tourists N, inversely proportional to the innovation cost F (θ), and proportional to the overpayment σ resulting from the mismatch of consumer preferences for product characteristics. The number of tourists and overpayments are not the focus of this paper; we are concerned with the fact that the "Digital Economy" can reduce the cost of innovation and thus facilitate the continuous entry of rural entrepreneurial agents.

In the theoretical analysis section, we establish a link between the "Digital Economy" and rural tourism entrepreneurship and use tourism product innovation as a mediating channel. The "Digital Economy" reduces innovation costs and promotes innovation, which in turn promotes entrepreneurial activity. We next test the linkage in the empirical analysis section.

Empirical analysis

In this paper, 150 counties in the Yangtze River Delta region (YRD) consisting of Jiangsu (JS), Zhejiang (ZJ) and Anhui (AH) provinces, which share similar cultural attributes and institutional environments, are selected as the sample. In addition, after more than 10 years of integrated development, the economic levels of different sub-regions in the Yangtze River Delta tend to converge. Therefore, this helps us to identify the net effect of the "Digital Economy."

Data

Independent variable

The independent variable is the level of "Digital Economy" development of each county. As mentioned above, we used the County Digital Countryside Index (2018) published by New Rural Development Institute of Peking University in conjunction with Ali Research Institute. This data is a cross section of the 2018. We chose three of the primary indicators ("Digital Infrastructure Index") ("DII" in short), "Rural Economy Digitalization Index" ("REDI" in short), and "Rural Governance Digitalization Index" ("RGDI" in short) as the values of the independent variables.

"Digital Infrastructure Index" mainly contains a measure of the level of rural information infrastructure, the level of digital financial infrastructure and the level of big data platforms, reflecting the level of government investment in the process of developing the "Digital Economy." "Rural Economy Digitalization Index" mainly contains the digitalization level of enterprise production, the digitalization level of industrial chain, and the digital marketing level of enterprises, which reflects the understanding and application of digital technology by market operators. "Rural Governance Digital Index" includes the level of digitization of government services. Unlike the Digital Infrastructure Index, this index reflects whether the government has improved its governance efficiency through digitization.

Dependent variable

The dependent variable was used to describe the entrepreneurial performance of the entrepreneurs in each county. We have selected three representative entrepreneurial performances, which are: (1) Number of new startups influenced by the "Digital Economy" in a given period, (2) Number of entrepreneurial exits influenced by the "Digital Economy" in a given period, and (3) Average life cycle of exited startups influenced by the "Digital Economy." Among them, we are most concerned about the indicator of the number of new startups.

The data comes from the National Enterprise Credit Information Public Disclosure System provided by the Chinese government. We searched for startups using "farmhouse" as a keyword—the Chinese name is "农家乐," similar to the European "family hotel." The "farmhouse" is a kind of small business that is widely found in rural areas and can provide food, accommodation, leisure and fun, etc. It is usually operated by rural residents using their own houses. The national enterprise credit information disclosure system can provide data on the "farmhouse" in each county, including the total number of farmhouses in a county at a given time, the start-up time of each farmhouse, the exit time of those that have been withdrawn, and the registered capital, address, and contact information of the farmhouse.

The digitalization of China's rural areas can be traced back to 2008 when the Ministry of Agriculture proposed "Opinions on Accelerating the Promotion of Rural Informatization" and 2009 when the National Tourism Administration started the "Rural Smart Tourism." In addition, considering that the Rural Digital Economy Index was released in 2018, we set the observation period of the sample from 2011 to 2020, which can completely cover the 12th and 13th Five-Year Plan periods of China. We calculate the values of three specific dependent variables: (1) Increase in entrepreneurship ("IIE" in short), the ratio of the average number of new "farmhouses "per year between 2011 and 2020 to the stock of "farmhouses" in 2018, using the ratio form to better control for industry. (2) Exit of entrepreneurship ("EOE" in short), the ratio of the average number of "farmhouses "exited each year between 2011 and 2020 to the stock of "farmhouses" in 2018. (3) Entrepreneurial life cycle ("ELC" in short), the average survival time of the exited farmhouses between 2011 and 2020.

Intermediate variables

The mediating variable is the level of differentiation of a county's rural tourism product, which comes from innovation. Due to the lack of abundant data on firms at the rural level in China, we use three proxy variables to describe the level of differentiation. The first proxy variable is the number of "National One Village, One Product Model Villages" (leisure tourism category) owned by a county. The selection criteria for "National One Village, One Product Model Villages" ("OPMV" in short) include "having more new industries and new business models" and "having distinctive brands," which can indirectly reflect regional innovation performance. The second proxy variable is the number of "China's Beautiful Leisure Villages" ("CBLV" in short) owned by a county. The selection criteria for "China's Beautiful Leisure Villages" include "having a variety of tourism products" and "products recognized by consumers," which can directly reflect regional innovation performance. The third proxy variable is the number of "National Key Villages of Rural Tourism" owned by a county. The selection criteria for "National Rural Tourism Key Villages" ("RTKV" in short) include a "well-developed tourism product system" and a "unique tourism theme," which is a direct indicator of regional innovation performance. It is important to note that the second and third proxies are provided by different departments of the Chinese government and can be used as references. A more detailed description can be found in Table 2.

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TABLE 2 Basic information and selection criteria for the three types of selected lists (excerpt).

Government sector	Name	Time (group)	Num	Criteria for selection (excerpt)
Ministry of Agriculture	National One Village, One Product Model Villages	2011–2020 (10 groups)	3,387	1. Promote product innovation through industrial integration 2. Already have a new product system and new business model 3. Industrial development has increased farmers' income
Ministry of Agriculture	China's Beautiful Leisure Villages	2010–2016; 2017–2021 (10 groups)	–*	1. Products widely praised by consumers. 2. There are various types of tourism products, such as leisure agriculture park, B&B, etc. 3. A number of travel brands have been created
National Tourism Bureau	National Key Villages of Rural Tourism	2019–2021 (3 groups)	1,199	1. High quality and variety of tourism products 2. Tourism products with a clear theme 3. Villagers get higher income because of tourism

*The official website of China's Ministry of Rural Affairs can only be consulted for the qualified list of "China's Beautiful Leisure Villages" from 2011 to 2016.

In addition, we provide statistical values for the independent, dependent, and mediating variables at the provincial level and at the YRD level in Table 3.

TABLE 3 Statistical values of independent, dependent, and mediating variables (proxy variables) at the YRD level and at the provincial level.

Variable	Name		YRD	JS	ZJ	AH
Independent	DII	Mean	80.48	78.12	87.92	75.70
		S.D	12.65	13.76	11.90	9.43
	REDI	Mean	53.13	55.84	58.74	46.75
		S.D	12.02	12.26	10.98	9.62
	RGDI	Mean	70.15	74.22	87.65	52.99
		S.D	19.74	13.31	11.22	13.53
Dependent	IIE	Mean	75.86	77.09	78.57	72.81
		S.D	12.56	10.35	9.88	15.10
	EOE	Mean	13.16	13.27	13.22	13.04
		S.D	5.36	4.86	6.81	6.39
	ELC(Month)	Mean	75.95	78.09	68.30	81.01
		S.D	14.16	13.51	15.96	9.73
Mediating	OPMV	Mean	0.32	0.28	0.43	0.24
		S.D	0.62	0.61	0.64	0.62
	CBLV	Mean	1.28	1.73	0.98	1.24
		S.D	1.25	1.55	1.10	1.09
	RTKV	Mean	0.19	0.15	0.21	0.18
		S.D	0.39	0.36	0.41	0.38
	Number of counties		150	38	51	61

Yangtze River Delta data does not include Shanghai sample; Beautiful Country 2010–2016 only qualified list.

Digital economy and entrepreneurial activity

The baseline model is shown below, as we focus more on new entrepreneurship, the dependent variable on the left side of the equation is the increase in entrepreneurship (IIE). The other two dependent variables need to be changed in form and are not repeated here.

$$\frac{\Delta IIE_C}{L_{C,2018}} = \beta\, Digital_c + \Gamma X_{c,2018} + \mu_i + \varepsilon_c$$

$\frac{\Delta IIE_C}{L_{C,2018}}$ represents the ratio of the average annual number of new "Nongjiale" in a county from 2011 to 2020 to the stock of "Nongjiale" in 2018, and the subscript c indicates a specific county. $Digital_c$ is a set of digital economy variables, using digital infrastructure index ("DII" in short), rural economy digital index ("REDI" in short) and rural governance digital index ("RGDI" in short), respectively. $X_{c,2018}$ is a set of control variables, including (1) the number of national 4A and 5A scenic spots in the county, in order to control the high-quality tourism resources; (2) GDP, in order to control the level of regional economy; (3) government financial expenditure, in order to control government behavior; (4) administrative area, in order to control the scale; (5) the area of facility agriculture, in order to control the level of agricultural development; (6) the number of service industry employees, in order to control the level of service industry development; (7) the topographic index, in order to control the possible differences of natural landscape; (8) the bank deposit balance, in order to control the capital abundance of the county; (9) the number of industrial enterprises above the scale, in order to control the characteristics of scale economy. In addition, we added provincial fixed effects, in order to control the tourism policies at the provincial level. Table 4 shows the baseline regression results.

In column A of Table 4, all three rural digital economy indicators show a positive and significant relationship with "Increased In Entrepreneurship" (IIE). The economic implication is that the higher the level of digital economy of a county, the more rural tourism entrepreneurship it will have in the 12th and 13th Five-Year Plan periods. In particular, an increase of 1 in the Digital Infrastructure Index (DII) increases the ratio of the number of entrepreneurship between 2011 and 2020 to the stock of rural tourism in 2018 (hereinafter referred to as "entrepreneurship ratio") by 0.433 percentage points. The Rural Economy Digital

TABLE 4 Baseline regression results for the digital economy and entrepreneurship.

	A:IIE			B:EOE			C:ELC		
DII	0.433***			0.037			0.086		
	(0.089)			(0.058)			(0.08)		
REDI		0.439***			−0.324***			0.211*	
		(0.109)			(0.058)			(0.099)	
RGDI			0.277**			−0.036			−0.009
			(0.086)			(0.067)			(0.071)
Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
F	5.11	4.89	3.17	3.35	9.30	1.78	3.33	3.71	3.36
Prob > *F*	0.000	0.000	0.001	0.000	0.000	0.036	0.000	0.000	0.000
R-squared	0.251	0.241	0.216	0.264	0.366	0.114	0.209	0.229	0.213
obs	150	150	150	150	150	150	150	150	150

*indicates significant at the 0.05 level,
**indicates significant at the 0.01 level.
***indicates significant at the 0.001 level.
1. The values of the first two dependent variables are multiplied by 100 when entering the regression. 2. All control variables such as gross regional product, resident deposits, fiscal expenditure, administrative area, and number of industrial enterprises above the scale are taken as logarithms.

Index (REDI) increases by 1, and the Entrepreneurship Ratio increases by 0.438 percentage points. An increase of 1 in the Rural Governance Digital Index (RGDI) increases the entrepreneurship ratio by 0.27 percentage points. Among the three independent variables, the rural economy digital index has the largest impact. Thus, the understanding and application of the digital economy and the digital transformation of the industry chain by enterprises have the strongest effect on promoting entrepreneurial activities.

In column B of Table 4, we find that only two digital economy index have a negative and significant relationship with "Exit of entrepreneurship" (EOE): the digital infrastructure index (DII) and the Rural Economy Digitalization Index (REDI). The economic significance is that the higher the level of digital economy in a county, the lower the number of entrepreneurial exits in the 12th and 13th Five-Year Plan periods. In particular, an increase of 1 in the Digital Infrastructure Index decreases the ratio of the number of entrepreneurial exits between 2011 and 2020 to the stock of farmhouses in 2018 (hereinafter referred to as the "exit rate") by 0.233 percentage points. The rural economy digitalization index increases by 1, and the "exit rate" decreases by 0.324 percentage points. The effect of rural governance digital index (RGDI) on the "exit rate" is negative but statistically insignificant. We can conclude that the understanding and application of the digital economy and the digital transformation of the industry chain can help entrepreneurs to stay in the market for a long time.

In column B of Table 4, the "Rural Economy Digitalization Index" (REDI) is negatively associated with "Exit of entrepreneurship" (EOE) and is statistically significant at the 0.001 level. The economic significance is that an increase of 1 in a county's "Rural Economy Digitalization Index" (REDI) decreases the number of entrepreneurial exits in this county by 0.324. "Digital Infrastructure Index" (DII) and "Rural Governance Digitalization Index" (RGDI) have no significant effect on entrepreneurial exits, and digital infrastructure index is weakly positively associated with "Exit of entrepreneurship" (EOE).

In column C of Table 4, we use the average life cycle of exited entrepreneurship (ELC) as the dependent variable, and only the effect of the "Rural Economy Digitization Index" (REDI) is significant and positive. The economic significance is that the higher the level of digitalization of the rural economy in a county, the longer the survival time of tourism start-ups in this county in the 12th and 13th Five-Year Plan periods. An increase of 1 in the index increases the survival time of tourism start-ups by 0.211 months.

Through columns B and C, we can conclude that the understanding and application of the digital economy and the digital transformation of the industry chain can help entrepreneurs to stay in the market for a long time.

Digital economy and product differentiation innovation: Mediation mechanism

Product innovation plays the role of a mediating mechanism and is the most important theoretical finding of this paper. The digital economy stimulates the emergence of innovative behavior and the formation of markets characterized by product differentiation, which in turn stimulates entrepreneurial activity. Because the process of product innovation for entrepreneurship has been verified by the product matching model, we focus on testing the impact of the digital economy on product differentiation innovation. The econometric model continues using equation (6), the difference being that the dependent variable changes and we obtain results using zero-inflated Poisson regression of the counting model Table 5 shows the regression results.

In column D of Table 5, the coefficients of all three digital economy indicators are positive, but only the effect of the "Rural Economy Digitalization Index" (REDI) is statistically significant. The economic significance is that an increase of 1 in REDI is associated with an increase of 0.024 in the number of "National

TABLE 5 Baseline regression results for digital economy and innovation.

	D: OPMV			E: CBLV			F: RTKV		
DII	0.005			0.004			0.018		
	(0.010)			(0.01)			(0.016)		
REDI		0.024*			0.01**			0.025**	
		(0.01)			(0.009)			(0.01)	
RGDI			0.011			0.002			0.016
			(0.011)			(0.007)			(0.012)
Wald $Chi^2(11)$	67.33	94.75	77.26	38.74	37.23	38.33	42.46	45.52	41.77
Prob > Chi^2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pseudo R^2	0.123	0.134	0.126	0.051	0.053	0.050	0.096	0.101	0.094
p-Value	0.634	0.074	0.318	0.713	0.397	0.767	0.274	0.023	0.159
obs	150	150	150	150	150	150	150	150	150

*indicates significant at the 0.05 level.
**indicates significant at the 0.01 level.
All test models include control variables and provincial fixed effects.

One Village, One Product Model Villages (Leisure Tourism)" (OPMV) in that county.

In column E of Table 5, the coefficients of all three digital economy indicators are also positive, but only the effect of the "Rural Economy Digitalization Index" (REDI) is statistically significant. The economic significance is that an increase of 1 in REDI is associated with an increase of 0.01 in the number of "China's Beautiful Leisure Villages "(CBLV) in that county.

In column F of Table 5, the coefficients of all three digital economy indicators are also positive, but only the effect of the "Rural Economy Digitalization Index" (REDI) is statistically significant. The economic significance is that an increase of 1 in REDI is associated with an increase of 0.025 in the number of "National Key Villages of Rural Tourism "(RTKV) in that county.

We found that among the three digital economy indicators, the Rural Economy Digitalization Index (REDI) has the largest and statistically significant impact on entrepreneurship and innovation. Therefore, we believe that entrepreneurial activity in this region will be boosted if companies better understand and use digital technologies and use data as an important input factor for production and sales, as well as if the industry chain changes business models through digital technologies.

Due to the important role of the "Rural Economy Digitalization Index" (REDI), we use it as the only independent variable in the endogeneity analysis and robustness tests below, and we use "Increased In Entrepreneurship" (IIE) as the only dependent variable.

Endogenous

The "Rural Economy Digitization Index" may be influenced by the size of the tourism market and entrepreneurial activity that already exists in a county; therefore, the independent variable and dependent variable appears to be mutually causal and lead to biased coefficients of the estimates. We use instrumental variables to address this issue, and we select the "Transportation Distance" between each county government site and the Hangzhou city government site as the instrumental variable. The reasons are as follows: first, Hangzhou is considered the birthplace of the digital economy in the Yangtze River Delta region, and according to the first law of geography, entrepreneurs in counties closer to Hangzhou are more strongly influenced by Hangzhou's digital economy thinking, such that the "Transportation Distance" is negatively correlated with the dependent variable. Secondly, except for the counties under the jurisdiction of Hangzhou, the markets of other counties are the neighboring cities in the immediate vicinity, and Hangzhou has little influence on their tourism development and naturally little influence on their entrepreneurial activities, so the "Transportation Distance" is not related to the dependent variable. "Transportation Distance" can only affect entrepreneurial activity by influencing the level of digitalization of the rural economy in other counties. In this paper, we use the minimum commuting time by car as the value of the instrumental variable and use two-stage least squares to test for endogeneity. The test results are shown in Table 6.

Column G of Table 6 shows the results of the first stage regression. After controlling for confounding variables in the baseline regression, the instrumental variable has a negative relationship with the "Rural Economy Digitalization Index" (−0.065) and is statistically significant at the 0.001 level. The economic significance is that the further a county is from Hangzhou in terms of commuting distance, the lower its level of rural economic digitalization.

In Column G of Table 6, we remove the residuals of the endogenous explanatory variables using instrumental variables and the new explanatory variable "REDI (re)" has a positive coefficient (5.875) that is statistically significant at the 0.001 level. The economic significance is that the "Rural Economy Digitization Index does" increase the number of entrepreneurship in a

TABLE 6 Endogeneity test: digital economy and entrepreneurship.

G: Results of the first phase		**H: Results of the second phase**			**I: Exogeneity test**		**J: Weak instrumental variable**	
	REDI		**REDI(re)**	**IIE**				
Transportation-distance	−0.065*** (0.011)			5.875*** (1.734)	Durbin (score) Chi²(1):	6.786	Partial-R^2	0.196
					p-Value	0.009	$F(1,140)$	34.212
Control	Yes	Control		Yes	Wu–Hausman $F(1,139)$	6.583	Prob > F	0.000
$F(9,140)$	14.29	Wald Chi²(9)		36.0.30	p-Value	0.011	Minimum eigenvalue statistic	34.212
Prob > F	0.000	Prob > Chi²		0.000			2SLS size of nominal 5% Wald test	16.38
R^2	0.4788	p-Value		0.001				
p-Value	0.000	obs		150				
obs	150							

***indicates significant at the 0.001 level.
1. The first stage is the regression of the endogenous independent variable on the instrumental variable, and the second stage is the regression of the dependent variable on the independent variable with the residuals removed. 2. The reference value used in the "2SLS Size of nominal 5% Wald test" is the key value at the 10% position.

county， corresponding to the results of the baseline regression in Table 4.

In column I of Table 6, the Hausman test was adopted for the exogeneity test. The results of the χ^2_J-test (6.786) and the F-test (6.583) are reported in the table, and the p-values indicate that the rural economy digitization index is an endogenous variable. Therefore, it is justified to use instrumental variables.

Column J of Table 6 shows the weak instrumental variable tests. We took two approaches, the summary of the first stage results and the Stock/Yogo weak instrumental variable test, respectively. The summary of the first stage regression shows that excluding the effects of other exogenous factors, the instrumental variables still explain 19.6% of the variation in the dependent variable with an F-statistic value greater than 10 and significant. Using simple criteria, we conclude that there are no weak instrumental variables. In the Stock/Yogo weak instrumental variable test, the value of "Minimum eigenvalue statistic" (which is 34.21) is significantly greater than the value of "2SLS Size of nominal 5% Wald test "(which is 16.38). Using the complex criteria, we conclude that there is no weak instrumental variable.

Further, we proceed to test whether endogeneity interferes with the impact of the "Rural Economy Digitization Index" on a county's tourism product innovation. The test we use remains the same two-stage least squares method. Because of the large number of mediating variables and to save space, we only present the second-stage results and some key statistical test information in Table 7.

We removed the residuals of the endogenous explanatory variable (REDI) using instrumental variables and obtained a new explanatory variable [REDI (re)]. Table 7 show that all

TABLE 7 Endogeneity test: Digital economy and product innovation.

	K: OPMV	**L: CBLV**	**M: RTKV**
REDI(re)	0.169** (0.053)	0.212** (0.059)	0.183** (0.055)
Durbin (score) Chi²(1):	8.954	9.907	9.112
p-Value	0.000	0.000	0.000
Minimum eigenvalue statistic	39.99	51.88	43.66
obs	150	150	150

**indicates significant at the 0.01 level.
All test models include control variables and provincial fixed effects.

three regression coefficients are positive and statistically restricted at the level of 0.01, further confirming the fact that the higher the "Rural Economy Digitization Index," the more counties have "National One Product One Village Characteristic Village"(OPMV), "China Beautiful Leisure Village"(CBLV) and "National Rural Tourism Key Villages"(RTKV), as well as, the higher the innovation of tourism products in this county.

Testing for spatial effects

We argue that spatial correlation may interfere with the impact of a county's digital economy on tourism product innovation and entrepreneurship in that county. The reasons are as follows: first, tourism landscapes are the basis of tourism, and some large-scale tourism landscapes (e.g., mountains, forests, and rivers) cover multiple counties, leading to a correlated

TABLE 8 Control space correlation.

	N: IIE	P: OPMV	Q: CBLV	S: RTKV
REDI	0.371**	0.022*	0.008*	0.019
	(0.104)	(0.010)	(0.004)	(0.009)
p-Value > $Chi^2(9)$	0.006	0.011	0.111	0.052
Rho	0.016	0.103	1.107	0.433
Sigma	11.08	13.59	17.21	14.88
(Buse 1973) R^2	0.139	0.196	0.265	0.203

*indicates significant at the 0.05 level.
**indicates significant at the 0.01 level.

tourism economy in the immediately neighboring counties. Second, neighboring counties generally share the same culture and frequent social exchanges, leading to similar market behavior characteristics of residents in these areas, as well as their innovative and entrepreneurial behaviors. Finally, visitors to one county often come from another region, so the digital economy of another region may affect tourism in that county. In summary, the data may be spatially dependent and the baseline regression results may be unreliable. Following the approach of Deller et al. (2022), this paper controls for spatial dependence through a spatial weight matrix. Table 8 show the new regression results.

Column N of Table 8 can be compared with column A of Table 4, and columns P, Q, and S can be compared with Table 5. We find that when controlling for spatial correlation, the coefficient of the Rural Economy Digitalization Index (REDI) becomes smaller but still positive and statistically significant at the 0.05 level. We can still get the conclusion that the digitalization index of rural economy promotes tourism product innovation and tourism entrepreneurship.

Sensitivity analysis (omitted variable analysis)

A problem that tends to arise in cross-sectional analysis is the bias of coefficients due to omitted variables. We finally use sensitivity analysis to test the possibility of this problem. The test is if there are omitted variables, how strong of an explanatory power does the omitted variable need to have to overturn the results of the baseline regression? Or how robust are the baseline regression results in the worst case scenario (where the omitted variable contains all the remaining variance of the explained variable)? To accomplish this task, we set a dummy omitted variable and assume that this omitted variable has three times the effect on the dependent variable than GDP (we use "GDP" for comparison because GDP is the most basic measure of the level of economic activity in a county). To save space, our focus remains on the relationship between the "Rural Economy Digitalization Index" and the "Increase In Entrepreneurship," the causal relationship of most interest in this paper. The results of the analysis are shown in Figure 2A,B.

In Figure 2A, the statistical significance of the effect of the "Rural Economy Digitalization Index" on the "Increase In Entrepreneurship" does not change in any way when we include the potential omitted variable of three times the explanatory power of GDP. In Figure 2B, the direction of the effect of the "Rural Economy Digitalization Index" on the "Increase In Entrepreneurship" does not change in any way when we include a potential omitted variable with an explanatory power 3 times that of GDP. Therefore, we consider the results obtained from the benchmark regression to be robust.

Conclusions and recommendations

This paper examines the impact of the Digital Economy on rural entrepreneurial activity and extends the perspective to a specific rural industry—tourism. We obtain the following important conclusions: (1) The Digital Economy promotes tourism entrepreneurial activity in rural areas, which is consistent with most of the literature on the digital economy (or digital technology). (2) A new mechanism for the Digital Economy to act on entrepreneurial activities was discovered—product differentiation innovation. The digital economy directly reduces the cost of innovation and thus stimulates innovative behavior, and a market characterized by product innovation will spontaneously stimulate more entrepreneurial activities. (3) The Digital Economy includes multiple dimensions, and it is the "Rural Economy Digitalization Index" that can work through intermediary mechanisms, other dimensions of the digital economy do not promote product innovation.

Based on the findings in (2) and (3) in the previous paragraph, we propose two policy recommendations: First, in the future, government investment could be directed away from infrastructure and toward the innovative capabilities of entrepreneurs. For example, improving entrepreneurs' understanding and application of digital technologies, promoting the digital transformation of business models in the tourism chain, and increasing the input of data elements in the production process. Second, existing policies to support funding for entrepreneurial activity may lead to market failures, i.e., short business life cycle or (and) high business exit. We believe that the government should focus in the future on how to provide a good market environment for operators' innovative behavior, thus addressing the current widespread lack of innovation and leaving how to increase entrepreneurship to market mechanisms.

The limitations and shortcomings of this paper are reflected in the fact that we do not consider whether the personal traits of entrepreneurs influence the mechanisms of action of the digital economy. This new study requires more micro-level data, and in the future we will try to use innovation survey data to study the innovation choices and entrepreneurial quality of existing entrepreneurs.

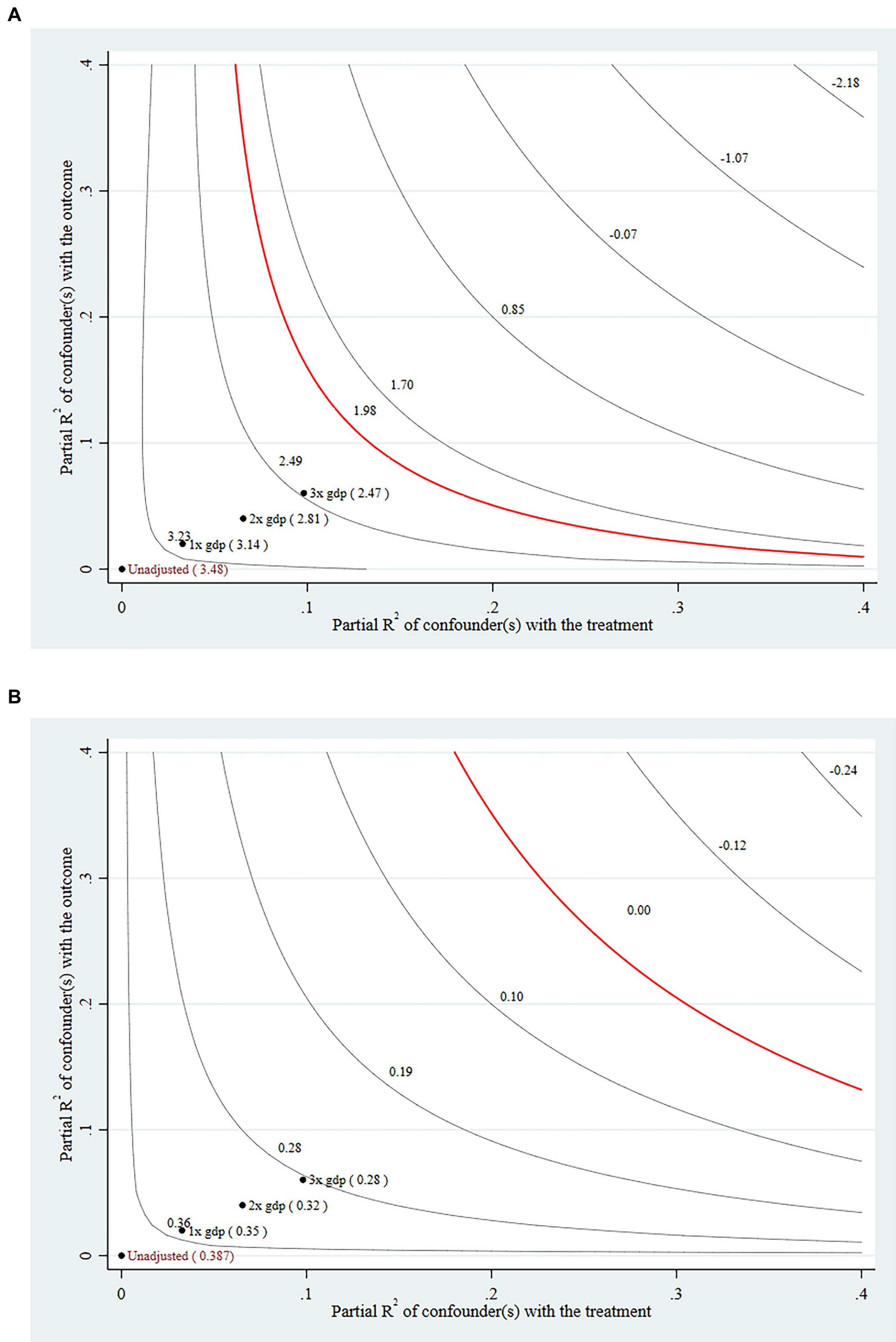

FIGURE 2
(A) The red line indicates the threshold at which the significance of the coefficients can be overridden, and when we successively add omitted variables with explanatory power, the threshold is not breached. The fact that the coefficients are significant in the baseline model is robust. **(B)** The red line indicates the threshold at which a positive coefficient can be overturned, and when we successively add omitted variables with explanatory power, the threshold is not breached. The fact that the coefficients are positive in the baseline model is robust.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

GT is responsible for the topic of the manuscript and the structure of the manuscript. FR is responsible for writing the manuscript and data analysis. JZ is responsible for finding the data. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Towards achieving the sustainable development goal 9: Analyzing the role of green innovation culture on market performance of Chinese SMEs

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Green innovation culture is essential to the Chinese 14th five-year plan aligned with sustainable development goal 9. This study examines the relationship between green innovation culture and market performance of Chinese small and medium-sized enterprises (SMEs). We evaluated hypothesis by taking a sample of 564 SMEs employees in China through an online survey. The structural equation modelling (SEM) method is used to analyze data. The findings showed that green innovation culture positively influence product and marketing innovation. Similarly, marketing innovation positively affects product innovation and market performance. In addition, product innovation has a substantial effect on market performance. The outcomes of this study imply that SMEs in emerging economies should concentrate on green innovation culture to improve their market performance. In addition, the identification of study limitations and suggestions for further research are also addressed for all stakeholders involved with SMEs.

KEYWORDS

green innovation, market performance, green innovation culture, marketing innovation, product innovation, small and medium-sized enterprises

Introduction

Over the years, regulators across the globe have been eager to set legislation and standards for green goods and services (Chai et al., 2021; Su et al., 2021). Due to increased industrialization, environmental concerns are becoming a significant concern for corporations, governments, and society (Cabral and Lochan Dhar, 2019; Yang et al., 2021). Various external causes pressure corporations to pay heightened attention to environmental management (Jia et al., 2021; Hao et al., 2022). One body of literature on sustainable development demonstrates that companies adopt green practices in response to societal and legitimate pressures; whereas another body of literature emphasizes that being pro-environmental brings substantial advantages, including assisting in increasing productive capacity and lowering costs, nature stewardship, and creating a favorable impression of the company (Qu et al., 2022; Xue et al., 2022).

Therefore, several businesses have acknowledged the significance of green innovation culture (GIC) and adopted it as a viable strategy for competitive advantage (Wong, 2017). China's small and medium enterprises (SMEs) have seen a substantial shift over the past few decades (Zheng S. et al., 2022). Buyers' knowledge and related legislation have generated a sense of urgency about environmental preservation. Before the advent of environment-related laws in many regions of the globe, the SMEs sector saw environmental management challenges as an unnecessary expenditure; some even viewed it as an impediment to the organization's development (Doghan et al., 2022). This has resulted in several environmental problems (Wu et al., 2021; Ren et al., 2022). Additionally, legislation and ISO standards, restrictions on the consumption of various harmful chemicals, waste electrical and electronic equipment, and consumers' sheer awareness of the environment make GIC a vital aspect of a business (Muisyo and Qin, 2021; Wang H. et al., 2021).

Prior research has shown that core skills are vital to enhancing organizational performance through knowledge-based initiatives to promote GIC (Shujahat et al., 2019; Chen et al., 2022). Additionally, GIC is the primary predictor of an organization's viability and enhancing long-term financial success (Ahmad et al., 2021; Qu et al., 2022). GIC helps to transform and identify new opportunities, offering companies a competitive edge by enabling them to provide superior products and services for potential clients, dramatically influencing how organizations operate (Doghan et al., 2022). Past studies explored the link between green innovation (GI) and company growth, and the effects of increased market performance (MRP) and new market innovation (MRI) are often emphasized (Chandra et al., 2021). The link between small and medium-sized enterprises (SMEs) and more influential organizations is more vital than that between major corporations. Due to their nature and employment size, SMEs play a critical role in the current marketplace. Due to their ability to innovate new items and procedures has a tremendous effect on the economies of countries in an international market that is becoming more competitive (Padilla-Lozano and Collazzo, 2022). Consequently, enhancing the innovative abilities and expertise of SMEs opens immense opportunities. GIC is crucial for competitiveness and provides extra advantages for the private sector's productivity and MRP (Khan et al., 2021).

In the current market of China, it is evident that the significance of SMEs has been expanding. The majority of China's SMEs were founded within the previous three decades. Following China's opening to the market economy in the 1980s as part of Deng Xiaoping's market-oriented reforms, private SMEs were finally regarded as crucial to the nation's economic growth (Fang et al., 2022). Large state-owned enterprises (SOEs) in China rapidly changed into small and medium non-SOEs due to the economic dynamics that influenced them till the end of 2004. Moreover, implementing a non-SOE marketing approach assisted in the growth of more SME businesses. China's economic growth is increasingly dependent on the development of SMEs. Approximately 99 percent of all companies are SMEs, which significantly enhance a country's economic growth and aid in expanding trade, commerce, and employment (Sharma et al., 2021). Considering this, SMEs remain confronted with numerous barriers to pursuing successful GIC. To enhance the MRP of SMEs, it is crucial to understand the factors influencing GIC (Yang, 2019). This research examines the relationship between GIC and MRP by employing the resource-based view (RBV) theory from a Chinese perspective.

To date, extensive research has concentrated on examining the relationship under the following domains. Although SMEs seem to be a trendy subject today, limited research studies have examined this phenomenon from emerging countries' perspectives (Awan et al., 2022). For instance (Muisyo et al., 2022) explored the relationship between GI and environmental performance with green transformational leadership and green human resource management. Similarly, Arici and Uysal (2022) highlighted the association between GI, leadership, and green creativity. Despite previous studies, this study emphasizes GIC as a success element for SMEs MRP (Li et al., 2020). This study aims to comprehensively understand GIC paradigms and how they enhance the MRP of Chinese SMEs.

This study has significant contributions, which are as follows. The first contribution is to underline the significance of GIC and MRI to product innovation (PRI) in SMEs. It is essential to remember that GIC is required throughout all stages of rivalry and it creates wealth in the business sector (Rubio-Andrés et al., 2022). Numerous studies show that SMEs invest mainly in process development instead of PRI. Consequently, this study focuses only on the influence of PRI on MRP (Gherghina and von dem Berge, 2018). According to erstwhile research, a GIC must be formed, sustained, and fostered if organizations are competitive and produce new products (Waqas et al., 2021). Although the research concentrates on MRI and GIC, the significance of GIC and the effect of MRI on PRI were not well addressed in the prior study (Sprong et al., 2021). Secondly, this research investigates the significance of MRI techniques and PRI in achieving sustainable MRP. This study's core argument is that MRI is essential when seeking to enhance MRP (Hussain et al., 2020). Marketing and PRI initiatives are significant components of MRI. Competitiveness has evolved into a critical element of market existence, but GIC initiatives produce more value and benefits, such as assisting a business to distinguish out from its rivals (Knut Haanaes, 2016). Lastly, this study is a pioneer because no previous study has been conducted in Chinese settings. Moreover, the emphasis of this research is to analyze the impact of innovative initiatives, such as GIC, on MRP of Chinese SMEs. This study adds to the existing body of knowledge by highlighting how effective MRP of SMEs can be achieved by fostering a unique relationship among GIC, PRI, and MRI under RBV theory (Hermundsdottir and Aspelund, 2021).

The rest of the research is organized as follows: The second section describes the literature review and formulation of hypotheses. The third section describes the methodology and research design. The fourth section contains findings and analysis. Section 5 concludes with a discussion of research results and policy implications, identification of study limitations, and recommendations for further research.

Review of literature and development of hypotheses

As stated earlier, GIC leads to the invention of a novel technique, whether the organization is tangible (e.g., the manufacturing of a fresh commodity) or intangible (Granstrand and Holgersson, 2020; Chunxiang et al., 2022). Alternates to the existing business method are necessary for developing and discovering sustainable manufacturing and living structures. A significant amount of study has been shown on PRI, its function within SMEs, and MRI due to the importance of GIC in corporate growth and development (Afriyie et al., 2019; Castillo-Vergara and García-Pérez-de-Lema, 2021). Several scholars say several critical factors determine SMEs' effectiveness. As per the cross-national study conducted by Wang and Juo (2021), robust marketing strategies, solid customer relationships, and competent leadership are all factors that lead to the SMEs efficient MRP (Castillo-Vergara and García-Pérez-de-Lema, 2021).

Al-Khatib (2022) explored seven substantial factors that contributed to the progress of SMEs, such as the ability to establish and maintain a technical advantage, the ability to identify and focus entirely on market segments, strong management, a significant "individuals interacting" framework, a competent customers' business relationship, and the strategic utilization of information systems. Capable leaders, solid client and customer connectedness, an encouraging and robust control system, marketing effectiveness, establishing and keeping skills, and the right approach are six crucial elements that influence the MRP of SMEs (El Baz et al., 2022). Although most SMEs can swiftly adjust to changing surroundings and fulfill shifting consumer demands by adopting GIC (Adam and Alarifi, 2021).

Consequently, investigations usually emphasize the factors that adversely impact or impede the market performance of SMEs. However, according to the research conducted in Korea (Akbari et al., 2022), uncertain acceptance, risk-taking, ecologic strategic plan and monitoring, heterogeneous organizational nature, and professional competence in all workplaces are among the most distinguishing characteristics between innovative and non-innovative SMEs. It is believed that inadequate finance and poor rates of return are the most significant obstacles. Organizations that emphasize research and development (R&D), employee training, and personnel interaction are more likely to innovate. This scenario has led to increased new goods, technological advances in products and processes, and a greater focus on concept generation (Khan et al., 2022).

China, the country with the fastest-growing market worldwide, is one of the most significant places to investigate GIC and its accompanying phenomenon. The government classifies SMEs primarily by the number of workers, frequently fewer than 500 in most situations (Pan et al., 2021). The SMEs Promotion Law of China (2003) sets up the classification guidance for SMEs. The description of SMEs in Chinese settings is complicated since it depends on various elements, including business type, size, annual turnover, and net assets.

This research investigates the links between MRI, GIC, PRI, and MRP in Chinese SMEs. Consequently, the rationale for investigating the creative pursuits of Chinese SMEs is strengthened because several SMEs from developing nations indicate that GIC, PRI and MRI are essential for MRP. This study aims to find the critical building elements for improving a theoretical framework by analyzing studies on GIC in SMEs. A resource-based view (RBV) illustrates how internal resources impact MRP and enhance competitiveness in SMEs. RBV is a perspective that examines how high-performing companies allocate their attributes to their personnel. In addition, the RBV may assist in acquiring a greater knowledge of the success of these SMEs than other organizations.

According to most academics, GIC-related structures affect the SME's MRP. This strategy was modified to accommodate the innovative character of SMEs from a creative standpoint. Several investigations used a variety of GIC-related structures as potential factors for model restriction. A business strategy, rivalry, technology, and culture are examples (Ali et al., 2021). On the other hand, innovation and marketing are essential to the success of many firms, as acknowledged in numerous management and marketing publications. Consequently, this research employs the GIC, MRI, and PRI criteria. The research framework is established by dividing GIC-related aspects into three main groups and studying how these elements affect the SMEs MRP.

Market performance

SMEs' personel, assets, and income all drop below the specific level. The definition of SMEs varies by nation and, in certain instances, by business type (Li et al., 2022; Ullah et al., 2022). In China, the purpose of SMEs is highly complicated as it appears that there is no one criterion. There are precise regulations on the overall assets of all manufacturing industry firms, such as those in gas, water, mining, construction, energy, and supply. Retail enterprises, transportation, hotels, and restaurants are considered SMEs; however, there are no asset restrictions. In contrast, the guidelines for the industrial sector for SMEs include no more than 2,000 employees and an annual turnover of a maximum of RMB 300 million. Their total assets must not exceed 400 million RMB (Zhang et al., 2022).

Operational distinctions between SMEs and large businesses have been widely studied previously. As described in the preceding paragraph, these distinctions develop concerning available resources and restrictions, ownership, decision-making, and the entire organization's size. As in similar businesses globally, the absence of leadership, financial limits, and opposition to transformation usually fail too many SMEs (Lu et al., 2022). Due to these and various competitive market factors, SMEs must concentrate on productivity, innovation, and marketing. Even though China's SMEs have overgrown over the past decade and have made significant contributions to the country's development, their growth has been hampered by the aforementioned sluggish interconnections, lack of technical innovation, the market in general, and restricted financial assistance (Lu et al., 2022; Wang et al., 2022). This highlights the significance of effective market innovation while attempting to sell innovative products on both domestic and international marketplaces (Xu et al., 2020; Zheng C. et al., 2022). MRP leads to the link between sales drivers, market share, and product and service revenue premiums (Muisyo and Qin, 2021). Prior study has demonstrated a significant association between GI and a firm's environmental performance. Whereas this study focused on the influence of GIC on SME MRP, relatively little attention was paid to the impact of GIC on SME MRP.

Green innovation culture

GIC as a shared set of beliefs, concepts, and values produced by a management group to mold corporate behavioral patterns toward accomplishing shared objectives. GIC can be regarded as a systematic organizational culture that perceives environmental protection as foundational and a cornerstone of the company's values (Chandra et al., 2021; Yao et al., 2021), assimilated into their mission statement in such a way that each team member in the firm internalizes a focus on environmental responsibility (Zheng et al., 2020; Khan et al., 2021). These GIC modifications play a crucial role in redefining the firm's perspective towards environmental challenges, and workers now become more responsible about these matters. If managers care more about environmental preservation, the GIC will grow (Liu et al., 2022; Qu et al., 2022). GIC alters traditional modes of thought and acts as a catalyst for change (Waqas et al., 2021). Thus, a GIC may play a crucial role in engaging the organization's workers in a more serious approach to environmental challenges (Zhu et al., 2022).

The formal structure of a GIC based on "eco-environmental ideals" may offer a company with essential insights for implementing environmentally friendly improvements in its operations (Wang and Juo, 2021). An organization's pro-environment policy may be translated into GI *via* its GIC. However, GIC is only effective if a company can address environmental concerns (Aastvedt et al., 2021). Being the world's biggest developing economy, China has become a global center for SMEs due to its GIC. China's GI falls into two distinct types. The Chinese government is significantly responsible for technological innovation due to its assistance of businesses *via* encouraging and facilitating laws. This includes programs such as deep-sea space exploration and quantum computing breakthroughs. A further thread is a commercial innovation enabled by technology (Wang M. et al., 2021). Fewer restrictions to transformation and a high rate of entrepreneurial activity seem to be very probable in the nation, adding to its GIC. Consequently, Chinese SMEs have devised new strategies for developing different channels and implementing new methods of marketing a product that consumers value (Rehman et al., 2021). Due to their enhanced GIC, SMEs may gain a competitive edge in boosting production and marketing techniques and achieving desired results. The evidence indicates a significant relationship between GIC, PRI and MRI. Thus, based on the above arguments, we hypothesized that;

> *H1a:* GIC positively influences the MRI of SMEs.
>
> *H1b:* GIC significantly affects the PRI of SMEs.

Marketing innovation

MRI is the introduction of a unique marketing approach comprising significant alterations to designing products or packaging, product endorsements, promotion of the product, or price. Product, and process innovations are more successful than marketing innovations, indicating that MRI complements product and process innovations rather than replaces them. As a result, MRI has the potential to lower costs or increase consumers' willingness to pay (Sharma et al., 2021). Modern MRI positively impacts sales and reduces costs, enhancing competitiveness. Consequently, MRI is defined as exploring creative and innovative solutions to issues and needs (Chouaibi et al., 2022).

PRI is essential in MRI since it draws new consumers with the prospect of novel and improved products and expands product lines and segmentation. Consequently, MRI and PRI are often associated with a favorable connection. Due to the intense internal and worldwide rivalry, Chinese SMEs are noted for their MRI strategies (Darwish et al., 2021). Due to the enormous variety and diversity of accessible items, businesses must always create novel and improved marketing strategies to distinguish and advertise their items. This enables an inexpensive and lower-quality item and expands its distribution. Likewise, building a robust connection between MRP and MRI is uncomplicated since MRI leads to recruiting new clients and retaining the attention of existing ones, therefore favorably affecting MRP. Thus, we established the following hypothesis:

> *H2a:* MRI positively influences the PRI of SMEs.
>
> *H2b:* MRI significantly influences SMEs' MRP.

Product innovation

Although GIC may be seen in various ways, the emphasis of this section of the article will be on PRI. PRI is often connected with introducing a novel and improved product in the market, considering the current and future demands of the existing customers. PRI endeavors are famous for the Chinese government's ongoing emphasis on technological improvements in goods and investment in research and development (R&D) (Gürlek and Koseoglu, 2021). To ensure and execute PRI, Chinese SMEs use a variety of approaches and tactics comprising process, cost, and technical innovation. China has generated a relatively limited number of unique product innovations from a global perspective. On the other hand, Chinese businesses are transitioning from progressive to dramatic breakthroughs due to their vast expertise with gradual developments. For instance, Sanyi Heavy Industry produces one of the most robust crawler cranes worldwide (Singh et al., 2022). Furthermore, to investigate this relationship, we develop the following hypothesis:

> *H3:* PRI significantly influences the SME's MRP.

Methodology

Development of the questionnaire

This research investigates four factors: GIC, PRI, MRI, and MRP among SMEs. All the factors were derived from earlier studies. The MRI items are taken from Padilla-Lozano and Collazzo (2022). The GIC items were taken from Gupta et al. (2016). The items of PRI were derived from Al-Abdallah and Al-Salim (2021). The items of MRP were taken from Mehralian (2022). A 5-point Likert scale was utilized to assess all items in which 1 represents strongly disagree, and 5 describes strongly agree.

Sample and procedure

Primary data was gathered through an online questionnaire survey to investigate the hypotheses mentioned above. The participants of this study are managers, owners, salespeople, and R&D directors from SMEs working in China who are responsible for implementing innovative business strategies. Six hundred sixty-eight persons from various SMEs were asked to participate in the survey; 564 valid and complete questionnaires were received, with a 84.4 percent response rate. All survey respondents were briefed on the purpose of the investigation. Thity-five percent of the sample comprised company owners, whereas 27% had no more than 5 years of experience. Approximately 75% of the enterprises surveyed are small businesses with 1 to 50 workers (the number of working people).

There are various reasons to focus specifically on SMEs. Firstly, they contribute significantly to international economic growth and wealth creation. In addition, SMEs foster the development of jobs, leading to the most positive atmosphere in expanding marketplaces. Ultimately, innovative initiatives provide SMEs with the requisite skills to shorten production cycles, increase their probability of survival, and compete in fierce competition.

Data analysis

AMOS (version 26) and SPSS (version 26) software packages are utilized to conduct statistical analysis. Structural equation modelling (SEM) is performed to examine the proposed hypotheses. SEM is a practical method for finding the connection between diverse variables that delivers reliable and valuable results (Steenkamp and Baumgartner, 2000) And has three significant benefits over older techniques. (i) A precise estimation of measurement error. (ii) The estimation of latent variables using observable variables. (iii) Verification of the model for evaluating and executing a pattern based on data compliance (Tanveer et al., 2021). In addition, the majority of multivariate techniques ignore computation error implicitly. Nevertheless, the SEM evaluates dependent and independent variables by accounting for computation error (Sardeshmukh and Vandenberg, 2013). Due to its reliability and robustness, the method yields precise and clear outcomes (Belaïd, 2017).

SEM enables the development of distinct indicator constructs per component and generates reasonable conclusions (Irfan and Ahmad, 2022). In addition, the error sections of the tested factors are measured. Therefore, the relationship between variables yields reliable results. In addition, it can examine complicated linkages and several hypotheses by integrating mean configurations and group evaluations, which other models and prototypes cannot do. Considering the benefits of SEM, we applied it in our research, as it is the most effective method for testing the link between all variables under investigation (see Table 1).

Results

Discriminant validity and correlation analysis

During the investigation, significant correlations between the variables were identified. The average variance extracted (AVE) square root was utilized to test the discriminant validity. AVE's square root is more significant than its correlation with other factors, supporting the findings' discriminant validity (Nureen et al., 2022). Comparing the AVE values to the maximum shared variance (MSV) values for each construct is an additional way to establish discriminant validity. If the AVE value for a particular construct exceeds the MSV value, discriminant validity is achieved (Fornell and Larcker, 1981). Our results corroborate this since every AVE value exceeds every MSV value. A convergent validity test was undertaken using item loadings and AVE to determine how strongly the items may be related (K.K., 2013). The data revealed that the variances of the latent variables remained larger than 50%, suggesting that the AVE values for each construct surpassed 0.50 (see Table 2).

TABLE 1 Sample characteristics.

Characteristics	Frequency
Position within the company	
Business owner	35
Other	22
Board of directors	24
HRM Manager	11
Marketing Manager	4
R&D Manager	4
Work experience	
Less than 5 years	27
6–10 years	22
11–15 years	23
6–20 years	11
21–25 years	7
More than 25 years	10
Organization's size	
Less than 10 employees	46
10–30 employees	13
31–50 employees	16
51–100 employees	7
100–300 employees	10
More than 300 employees	8

TABLE 2 Descriptive statistics and correlations.

Variable	GIC	PRI	MRI	MRP	AVE	MSV
GIC	**0.744**				0.553	0.551
PRI	0.230	**0.842**			0.708	0.123
MRI	0.742	0.221	**0.779**		0.607	0.551
MRP	0.297	0.351	0.177	**0.715**	0.511	0.123

Bold values is square root of AVEs.

Reliability analysis

The reliability of the item was evaluated using Cronbach's alpha. The reliability of the data was validated by Cronbach's alpha values that exceeded the suggested minimum level of 0.70 (Nunnally, 1978). Using the composite reliability (CR) technique, the item's consistency across all variables was examined. Results indicate that CR values above the minimum threshold value of 0.70. CR levels exceed the minimum permitted threshold of 0.70 (Joe et al., 2017). Consequently, the results are shown in Table 3.

Structural model and results of hypotheses

We used SEM and covariance-based curve assessment techniques to examine the model's connections. The study yielded a high *f*-value, suggesting that all links are linear. Several fitness tests were also conducted to guarantee that the data matched the structural framework (see Figure 1). The goodness-of-fit indices reveal that the data of this study is well-fitted. Figure 2 shows a path diagram of the SEM. A positive and significant correlation was found (β = 0.032, p 0.05) between the GIC and MRI. As a result, H1a is accepted. A significant association between GIC and PRI was established (β = 0.081, p 0.1). Hence, H1b was accepted. Likewise, a significant relationship between MRI and PRI was established (β = 0.075, $p < 0.1$). As a result, H2a was accepted. The MRI estimates (β = 0.036, p 0.01) reveal a substantial correlation with MRP, indicating that MRI favorably influences MRP. Consequently, H2c was confirmed. H3a was also approved, since PRI affects MRP strongly (β = 0.075, $p < 0.05$). The results of the hypothesis are shown in Table 4.

TABLE 3 Factor loading and discriminant validity.

Variable	Items	Standard loadings	Cronbach- α	CR
Green innovation culture			0.902	0.832
	GIC 1	0.782		
	GIC 2	0.825		
	GIC 3	0.879		
	GIC 4	0.865		
	GIC 5	0.854		
Product innovation			0.851	0.924
	PRI 1	0.763		
	PRI 2	0.828		
	PRI 3	0.764		
	PRI 4	0.808		
		0.728		
Marketing innovation			0.924	0.885
	MRI 1	0.754		
	MRI 2	0.726		
	MRI 3	0.740		
	MRI 4	0.754		
Market performance			0.916	0.807
	MRP 1	0.724		
	MRP 2	0.744		
	MRP 3	0.686		
	MRP 4	0.704		

CMIN/DF: 2.358; GFI: 0.967; CFI: 0.972; NFI: 0.963; IFI: 0.978; RMSEA: 0.049; AGFI: 0.962; RMR: 0.47.

Discussions and policy implications

GIC seems to be the driving force behind attaining organizational objectives in the current competitive marketplace. In China's SMEs, GIC looks crucial for developing R&D and

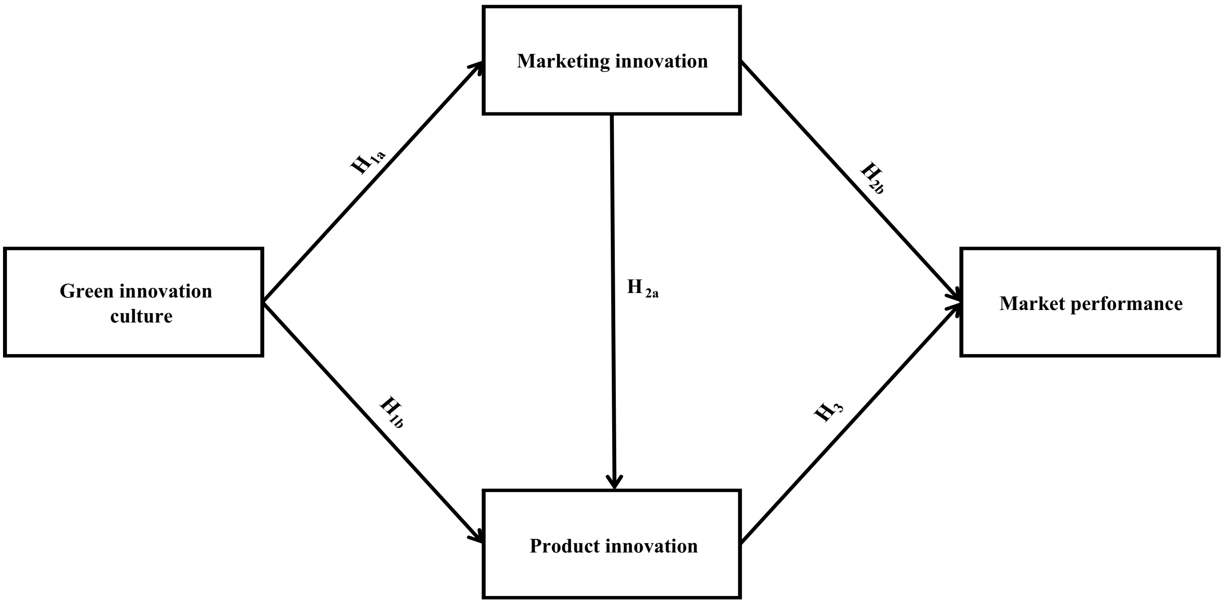

FIGURE 1
Depicts the study's research framework.

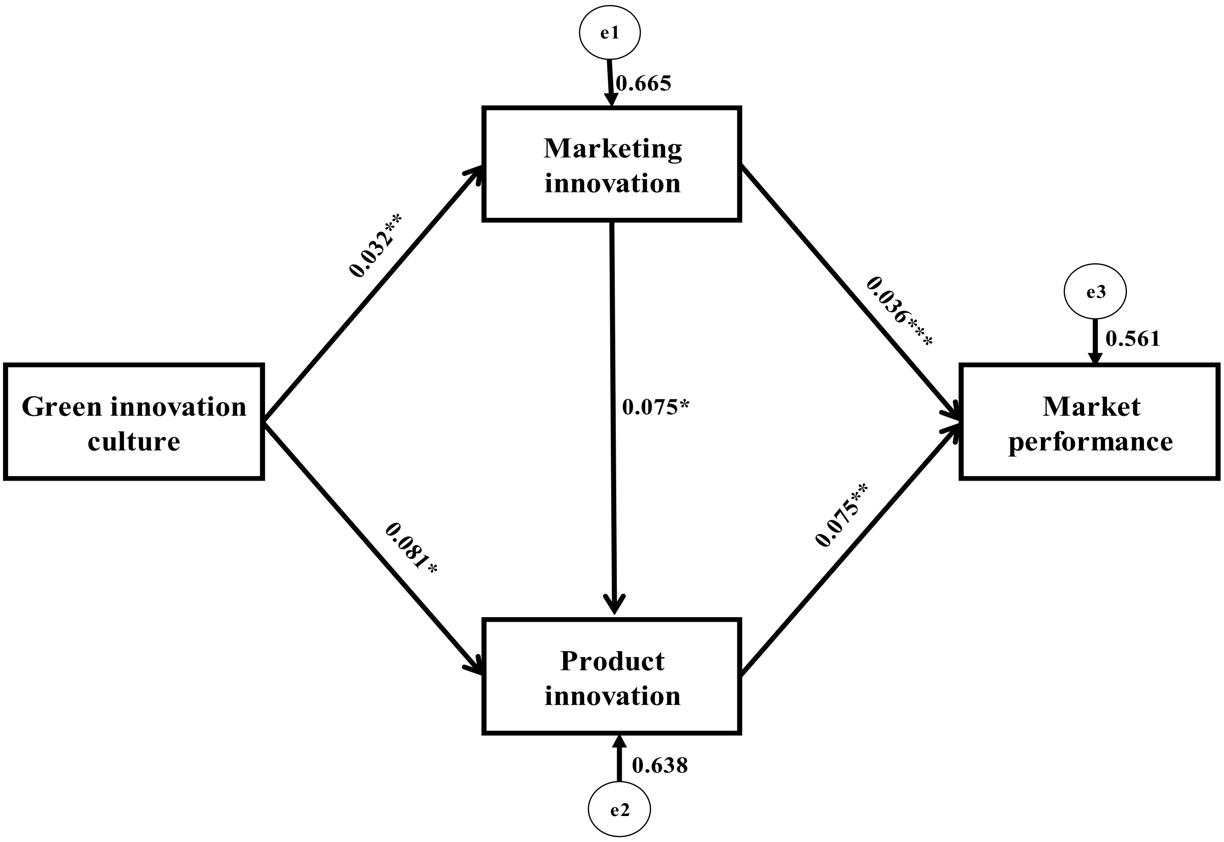

FIGURE 2
Path diagram of structural equation modeling. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

implementing market strategy. Likewise, MRI knowledge may result in PRI and enhanced SMEs MRP. A corporation requires produced items to be efficient. Customers want a high-quality product at a low price, and future generations need a safe environment. Awareness of environmental issues has expanded due to the global climate catastrophe, which has led both consumers and governments to enact legal rules on this topic. Consequently, the accompanying pressure intensified market rivalry and prompted businesses to seek inventive solutions. The literature emphasizes that GIC gives a competitive advantage by enhancing the creation of new products and processes (Tariq et al., 2017). However, businesses confront risks such as ecological repercussions, laws, consumer expectations, and environmental uncertainty (Rayna and Striukova, 2019) while participating in GIC activities. Due to these risks, it may take businesses a considerable amount of time to get a return on their investments in GIC operations.

In addition to these factors, the conviction that GIC helps create environmentally friendly goods and processes and improves MRP inspired us to undertake this research. We analyzed the impact of GIC, MRI, and PRI on the MRP of Chinese SMEs. The findings showed that GIC could help SMEs to meet diverse customer needs, provides a unique product advantage, facilitates the development of new business models and better business opportunities, enhances the corporate image and improves MRP, and can help businesses gain a competitive advantage (Ahn et al., 2019), companies will benefit from investing in this direction.

Theoretical implications

SMEs' survival depends on their culture, capabilities, and values. This study discusses Chinese SMEs' success in considering GIC, MRI, and PRI. The findings of this research are meant to contribute to the current literature on organizational dimensions, SMEs, and GI from a Chinese perspective. It significantly contributes to research on the SMEs MRP by exploring GIC frameworks in depth. This research model describes the relationship between SME GIC, PRI, MRI, and MRP. The findings indicate that GIC leads to MRI and PRI (H1a and H1b). Moreover, GIC is necessary for managerial, marketing, and organizational growth in competitive marketplaces.

GIC in Chinese SMEs had a favorable effect on their products' marketing, R&D, and performance. When a company's GIC is well-developed and diversified, it may not only foster the creation of creative concepts and goods but also devise marketing methods that capture customers' attention. Additionally, GIC usually facilitates design and development procedures. According to the study, MRI shows a significant and positive connection with PRI and MRP (H2a and H2b). As per prior research, MRI significantly impacts MRP, firm profitability, and SMEs growth.

In contrast, this work improves previous studies by investigating MRI in an integrated approach focusing on SMEs MRP. When the creation and new product marketing are performed correctly, they are productive. Consumer awareness is lacking when a commodity is initially launched into the marketplace. Consequently, firms will want cutting-edge items to display and support them, culminating in MRI. Several studies have shown that PRI is crucial for the sustainable development of new goods, operational efficiencies, and market share expansion. This research shows a strong and substantial relationship between PRI and MRP (H3).

Moreover, the outcomes of this study indicate that GIC and MRI are closely related to PRI in SMEs settings. The research outcomes offer academics a valuable perspective, suggesting that GIC promotes SMEs to differentiate their goods from their rivals. This research contributes to the current GIC literature by enhancing knowledge of the relationship between GIC and the MRP of SMEs. Particularly, it investigates the impact of MRI and PRI on MRP.

TABLE 4 The structural model.

Hypotheses	Hypotheses paths	β-value	f-value	Result
H1a	GIC → MRI	0.032**	148.2***	Accepted
H1b	GIC → PRI	0.081*	187.7***	Accepted
H2a	MRI → PRI	0.075*	242.6***	Accepted
H2b	MRI → MRP	0.036***	19.8***	Accepted
H3	PRI → MRP	0.075**	341.6***	Accepted

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Managerial implications

This research examines the effects of PRI, MRI methods, and market expansion on the administrators of SME organizations. Initially, SMEs should make efforts on their MRI to gain a competitive advantage by fostering a GIC inside the firm. In the context of generating innovative and novel items, the management of SMEs must create new products and attain exceptional MRP. The research results also suggest that SMEs must attempt to maintain their assets to develop GIC, MRI, and innovative processes. These insights help managers to achieve improved MRP. SMEs must invest in promotional methods and build more substantial marketing initiatives throughout their firms to enhance their PRI skills. Furthermore, SMEs should be receptive to this GIC due to their technological environment and corporate branding activities, strengthening this ability to promote GIC for effective MRP.

As shown, the approach outlined in the research enables managers to adopt a new vantage point on how SMEs blend MRI and GIC to create effective MRP. Product and marketing development may flourish from incorporating a GIC into the firm's structure. Therefore, managers may shape workers' perceptions, attitudes, and acceptance of creative ideas to enhance MRP.

Conclusion

This research employed the RBV theory to comprehend how GIC, PRI, and MRI may enhance the MRP of Chinese SMEs. The results demonstrate that managers in emerging economies must pay more attention to the GIC, MRI, and PRI. They must increase their GIC spending. This research reveals the relationship between GIC and emphasizes the significance of MRI and PRI for SMEs' MRP. SEM tests have supported the link between GIC, MRI, PRI, and MRP. In addition, Chinese SMEs are less sophisticated and superior at embracing GIC than their counterparts in industrialized countries. Several Chinese SMEs are subject to stringent environmental restrictions imposed by the government and local and international consumers. Due to consumers' belief that GIC is a fast answer to these issues, GIC has been employed primarily to meet customers' desires, needs, and requirements. The developed countries, on the other hand, put a heavy focus on the GIC, PRI, and MRI because they recognize that without applying these factors, they would fail to achieve their intended objectives. They will not fulfill the client's requirements.

In contrast to earlier studies, this study includes limitations that provide areas for further exploration. It was difficult to obtain data through direct surveys because of the COVID-19 epidemic. Thus, we employed social media or email for data gathering, and future studies on the targeted respondents may include direct surveys. Second, it is suggested that a random sample method be employed to collect data since the snowball technique used in this study offered a risk of brief demonstration and might influence the interpretation of findings. The generalization restriction is the third. This research is conducted in an emerging country (China). The GIC, MRI, PRI, and MRP may vary in industrial environments and be influenced by the unpredictability of environmental contingency. Future researchers must include other potential variables in the relationship between GI and MRP, such as corporate social responsibility, environmental strategy, and green intellectual capital.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

This study was reviewed and approved by Ocean University of China (protocol code 704–3 on 13-09-2021). The patients/participants provided their written informed consent to participate in this study.

Author contributions

CW: conceptualization and writing – original draft. XC: formal analysis, data handling. XS: variable construction, software, methodology, and writing – review and editing. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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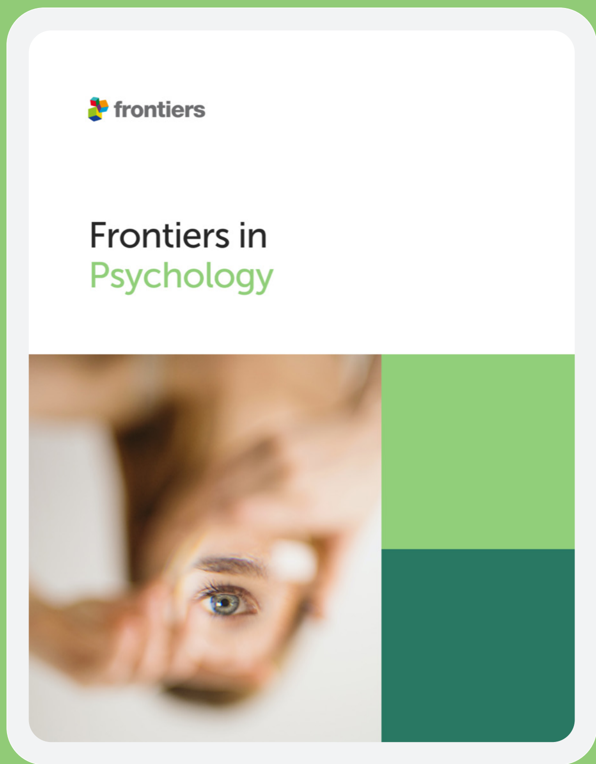

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