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Corporate environmental management, climate change and sustainable development

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Corporate environmental management, climate change and sustainable development

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Visual analysis of low-carbon supply chain: Development, hot-spots, and trend directions

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A low-carbon supply chain is generally a clean practice to achieve carbon peak and neutralization; it transforms supply chain management into a green economy, aiming to reduce energy consumption, reduce pollution and achieve sustainable development in all parts of the supply chain. However, there are few specific reviews of low-carbon supply chains to date. Therefore, this article provides a comprehensive analysis of the literature on low-carbon supply chains, explores the current knowledge system, evolution trend of topics, and future research directions, and enriches the green economy framework. A systematic analysis was conducted using bibliometric and content analysis. Up to 1,811 articles from 2003 to 2021 were selected, discussed, and analyzed. This study found that the low carbon supply chain is a growing research topic. Some influential authors, the geographical distribution of articles, and subject categories in this field were also identified. Next, five clusters, which are logistics management, carbon accounting, driving forces, sustainability management, and barriers, were defined using exhaustive content analysis. The evolution trend of significant topics, mainly including global value chain, additive manufacturing, deterioration, and decarbonization, was explored. Finally, we proposed a future research agenda for low-carbon supply chains and further deepened the green economy's knowledge structure.

KEYWORDS

bibliometrics, low-carbon supply chain, sustainable management, climate change, green economy

1 Introduction[1]

Low-carbon supply chain (LCSC) was originally raised in 2010. It aims to strike a balance between carbon reduction, economic performance, and social welfare (Govindan and Sivakumar, 2016; Yenipazarli, 2016). In particular, with the increased concerns about global climate change, energy consumption, and environmental awareness, as well as a consensus on carbon peaking and carbon neutrality targets, LCSC has presented an

1 GHG, greenhouse gas; LCSC, low-carbon supply chain; LCA, life cycle assessment; WOSCC, web of science core collection

enormous opportunity for international climate action within the industry (BCG, 2021; WEForum, 2021). Since it not only emphasizes the role of carbon reduction and energy efficiency in logistics management (Khan et al., 2019) as well as the role of coordination and innovation in sustainable management (Sharma et al., 2022), but also identifies carbon emission pathways through carbon accounting methods (Benjaafar et al., 2013). By implementing an LCSC, companies can meet carbon emission standards, achieve market competitiveness (Chen and Wang, 2017; Manupati et al., 2019), be environmentally friendly (Zhou X. et al., 2020), and increase social welfare (Tang and Yang, 2020). Therefore, as an emerging field, the concept and application research of LCSC is in the process of exploration, practice, and development.

The concept of the LCSC is derived from green supply chain and environmentally responsible supply chain, aiming to reduce CO2 emissions and energy consumption in supply chain management (Hsu et al., 2014; Das and Jharkharia, 2019). Unlike green supply chains, LCSCs are designed to reduce carbon dioxide emissions and improve energy efficiency (Jassim et al., 2018). In addition, as an extension of the green supply chain, the LCSC aims to highlight the use of supply chain management methods to indirectly help companies reduce their carbon emissions (Das and Jharkharia, 2018). Combining the above definitions, the concept of LCSC in this paper underlines the reduction of carbon emissions in logistics management, the coordination and innovation in sustainable management, the barriers and drivers in the implementation process, and monitoring and tracking of carbon emission pathways among the supply chain.

In principle, LCSC emphasizes supply chain management strategy and requires enterprises to adopt low-carbon strategies to redesign the supply chain to meet carbon emission standards and achieve market competitiveness (Chen and Wang, 2017; Manupati et al., 2019). Most importantly, Calkins (1996) first introduced a life cycle assessment (LCA) to study the product life cycle. Nicholson et al. (2014) used this approach to calculate carbon footprint of the supply chain. Moreover, it is an effective method for identifying carbon hotspots and helping managers make low-carbon decisions (Wiebe, 2018). Consequently, carbon accounting has promoted the development of the LCSC. Similarly, various carbon reduction tools have been used in this field in recent years. For instance, firms use alternative fuels such as biomass energy to reduce greenhouse gas (GHG) emissions during production and transportation (Brennan and Owende, 2010). Carbon capture, absorption, and storage technologies neutralize the emissions generated by business activities (Hasan et al., 2014). Moreover, carbon certification supports upstream and downstream supply chains in reducing emissions. On this basis, the carbon labelling system promotes companies' initiatives to reduce carbon emissions by influencing consumers' low-carbon purchasing behavior (Acquaye et al., 2015).

Drivers such as consumer low carbon preferences and government low carbon policies are crucial for enterprises implementing LCSC (Wang et al., 2016; Zhou et al., 2016; Ji et al., 2017; Kang et al., 2019). Although the LCSC is a better choice for enterprises considering consumers' low-carbon preferences, the investment cost in low-carbon technologies increases, making it difficult for them to carry out low-carbon management when they pursue maximum profit effectively. To address this issue, the government's carbon labelling technology allows consumers to identify low-carbon products to reduce information asymmetry (Liu et al., 2016). In addition, the government's low-carbon policy needs to consider not only the effectiveness of corporate emissions reduction but also fairness concerns and social welfare (Zhou et al., 2016). Similarly, several challenges exist and also need to be resolved, such as demand uncertainty (Peng et al., 2020), lack of information sharing (Nakajima et al., 2015), and lack of capital or resource for LCSC (Hitchcock, 2012).

Despite LCSC has been discussed widely in the literature, further research on exploration of drivers and barriers and the role of synergy and innovation for sustainable management is necessary. Although an increasing number of scholars have begun investigating the logistics management, drivers of LCSC and the application of carbon accounting, a systematic understanding of green economy framework from the supply chain management perspective is still limited. This study fills that research gap.

Literature review is significant for developing specific concepts or research topics in different domains (Palmatier et al., 2018). In particular, systematic literature review, which integrates and systematically analyzes existing research, identifies research gaps and establishes a knowledge framework system (Marabelli and Newell, 2014). On this basis, the bibliometrics method, as a powerful visual analysis tool, innovatively integrates massive literature data through computer algorithms. This method introduces a more objective measure for the evaluation of scientific literature, which increases the preciseness of scientific literature review and reduces the bias of researchers by aggregating multiple scholars' opinions in a field (Zupic and Cater, 2015). In addition, the bibliometric method mainly includes performance analysis and science mapping. Performance analysis helps researchers identify individual, institutional, journal, and national publication performance; science mapping reveals a research field's structure and dynamic development (Zupic and Cater, 2015). Compared to traditional and systematic literature reviews, bibliometric is a more scientific and intuitive approach. Therefore, it is necessary to conduct the publication performance and science mapping in the low-carbon supply chain field using bibliometric method. Nowadays, bibliometric method is widely used in various research fields, mainly

TABLE 1 Literature review articles related to the LCSC.

Author (year)	Main findings of review	Methodology	Sample size	Years cover
Das and Jharkharia (2018)	Authors found that all supply chain functions such as supplier selection, inventory planning, network design and logistics decision were redefined by considering the issue of carbon emission	Content analysis	-	2000–2017
Waltho et al. (2019)	Authors found four policies such as carbon cap, carbon offset, cap-and-trade, and carbon tax can achieve carbon emissions in supply chain operations	Traditional analysis	105	2010-mid 2017
Chelly et al. (2019)	Authors identified the sources of carbon emissions in different parts of the supply chain and model them accordingly by combining legislative and consumer constraints	Content analysis	83	-
Jabbour et al. (2019)	Authors analyzed the vital motivations, drivers, and barriers of low-carbon operations management	Content analysis	58	-
Shaharudin et al. (2019)	Authors found that LCSC field was mainly focused on supply chain practices and energy management	Network analysis and content analysis	2,199	Till 2018
Zhou et al. (2021)	Authors identified facility location, supplier and low carbon technology choice and investment, production planning, transportation decisions, pricing decisions, joint decisions and supply chain coordination under carbon taxes	Bibliometric analysis and content ananlysis	273	2010–2019

including green supply chain management (Fahimnia et al., 2015), supply chain digitalization (Seyedghorban et al., 2020), and sustainable supply chain (Beske-Janssen et al., 2015).

Many authors (Das and Jharkharia, 2018; Chelly et al., 2019; Jabbour et al., 2019; Waltho et al., 2019; Zhou et al., 2021) have contributed to the reviews on LCSC. Table 1 shows the review articles related to this field. These reviews are extensive and cover carbon reduction issues in supply chain operations. For instance, Das and Jharkharia (2018) redefined supply chain functions under carbon emission using content analysis while lacking quantitative analysis. Shaharudin et al. (2019) focused on supply chain practices and energy management using bibliometric analysis. Still, they ignored the important impacts of drivers and barriers to LCSC. Other scholars have focused on the drivers and barriers in LCSC. For example, Waltho et al. (2019) provided an overview of LCSC operations management based on four government policies. Zhou et al. (2021) presented an extensive review of this area based on a carbon tax perspective. Jabbour et al. (2019) focused on the drivers and barriers in the LCSC operation process while lacking quantitative analysis. These reviews have made a significant contribution to this topic. However, no comprehensive review was found that exclusively reviewed LCSC, combining qualitative and quantitative methods, based on a systematic and comprehensive perspective from supply chain management, carbon accounting, drivers and barriers. In addition, most of these reviews provide a systematic overview of management practices in this field while being short of further exploration of the theoretical framework. Thus, to provide an overall view of the current status, evolution trend, and research opportunities in LCSC studies, we conduct holistic bibliometrics and content analysis focusing on this domain, combining quantitative and qualitative analyses. Our study adopts a multidimensional and comprehensive perspective of the LCSC domain. It includes logistics management, carbon accounting, driving forces, sustainability management and barriers, topics that lack a systematic discussion in previous research. Moreover, this study constructs a green economy framework based on the supply chain perspective. These are the innovation of this paper.

The purpose of this study is, thus, to explore the literature on LCSC through a systematic analysis, provide new entrants with a detailed knowledge base, help supply chain researchers obtain in-depth insights, and provide supply chain managers with practical low-carbon strategies. Several research questions (RQs) were formulated:

- RQ1: What is the current status of the literature on the publication trends, influential authors, geographical distribution of articles, and the subject categories of LCSC?
- RQ2: What are the main research themes regarding LCSC?
- RQ3: What are the evolution trends and upcoming topics in LCSC-related fields?
- RQ4: What are the opportunities for future research, and how the green economy is framed in LCSC, as derived from our analysis?

Therefore, to answer the above questions, using the combination of bibliometric and content analysis methods, the information presented in this study aims to analyze the development status, research hotspots, topic trend, and future research directions of the LCSC as well as the theoretical framework of green economy from the perspective of the supply chain. Bibliometric analysis is scientific research based on statistics to sort out knowledge, construct knowledge frameworks, and capture the state of the art of the domain (Chen, 2017). In this study, one search was based on the Web of Science Core Collection (WOSCC) database for a total of 5,111 articles. We started by categorizing the 5,111 papers from journals published from 2003 to 2021 and leaving 4,574 articles. Further determining the most relevant publication, the number came down to 1,811. Some influential authors, the geographical distribution of articles, and subject categories in this field were also identified by using Bibexcel. Next, VOSviewer was employed to reveal research hotpots and five clusters were defined, and the evolution trend of important topics was explored using Bibliometrix R-package. Finally, we proposed a future research agenda for low-carbon supply chains and further deepened the knowledge structure of the green economy. The main contribution of the study is not only providing a scientific quantitative and qualitative approach to grasp generalized science research but also demonstrating the current status and hot-spots, research trends and future research directions in this field for researchers who are interested and constructing a green economy framework from a low-carbon supply chain perspective.

The remainder of this article is organized as follows. Section 2 presents the methods and data. The characteristics analysis, topic clusters analysis, and the research trends of LCSC are shown in Section 3. Section 4 presents a discussion and outlines future opportunities. Finally, section 5 draws conclusions and limitations.

2 Methods and data

2.1 Methods

Content and bibliometric analysis were employed in this paper to explore the literature on LCSC. Moreover, the BibExcel, VOSviewer and the Bibliometrix R-package were used to perform bibliometric analysis.

Content analysis, a valid qualitative research technique, is generally performed to make inferences from data based on the context (Hsieh and Shannon, 2005; Krippendorff, 2018). Advanced research and popular ideas were refined from existing papers on subtopics in this field. Bibliometric analysis is a popular and rigorous quantitative method for analyzing and exploring large volumes of scientific literature (Donthu et al., 2021). It is especially used to systematically study research status quos, hotspots, evolution trends, and upcoming changes in a specific field (Cobo et al., 2011). Several bibliometric methods were used in this study, including characteristic, theme cluster, and trend topic analysis.

The characteristic analysis clearly shows the basic information of the research field. This analysis was carried out using BibExcel, a convenient and robust software that accepts documents downloaded from the Web of Science (Ruas and Pereira, 2014). Its unique feature is that the processed files can be quickly imported into Excel for further analysis (Persson et al., 2009). Relevant information, such as the year of publication, leading author, country, and subject category, were extracted for further analysis.

Theme cluster analysis provides holistic cognition of scientific outputs (Rodriguez and Laio, 2014) and detects hotspots in a specific field. VOSviewer (Leiden University, Netherlands), an excellent visualization tool, was employed in our analysis. The algorithm of this software is based on the principle of similarity (Rodriguez and Laio, 2014). Compared to other visualization tools such as SPSS, Pajek, and Gephi, VOSviewer has unique advantages in constructing and visualizing scientific maps, especially for describing complex network structures simply and understandably (van Eck and Waltman, 2010).

It is necessary to capture topic trends based on their importance over time, so a trend topic analysis has a unique advantage in helping scholars identify evolving research topics and dynamics in a specific field (Sharma et al., 2021). Bibliometrix R-package, a unique open-source tool, was used to investigate trends. This technique is programmed in R and is flexible and up-and-date, thus supporting a comprehensive scientific map analysis (Aria and Cuccurullo, 2017).

2.2 Data collection

This study included articles on LCSC retrieved from the WOSCC database. This database was selected for its pioneering content, high scientific impact, and quality-oriented data for scientific bibliometric analysis (Chen et al., 2017). To ensure the reliability of the data source, our analysis followed three steps, as Tranfield et al. (2003) suggested: 1) defining keywords; 2) determining the criteria for screening; and 3) improving sample quality. The detailed process is illustrated in Figure 1.

First, we defined keywords for ‘low carbon’ and ‘supply chain*’. We obtained the possible keywords for this topic by browsing the top 500 records, which were retrieved from the initial keywords search above, in each subject classification. We further limited the keywords related to “low carbon” to make the results more accurate, such as expanding this keyword to “carbon policy”, “carbon footprint”. In addition, we also used “GHG”, “CO_2” instead of “low carbon” to make the search information more complete. Thus, we ended up with the following search string was used in WOSCC: [TS=(“net-zero carbon” OR “low carbon” OR “decarbon*” OR “peak carbon” OR “carbon peak” OR “carbon neutral*” OR “carbon emission*” OR “carbon tax*” OR “carbon trad*” OR “carbon footprint*” OR “carbon pric*” OR “carbon cap” OR “carbon market*” OR “carbon management” OR “carbon label*" OR “greenhouse gas” OR “GHG” OR “CO_2 emission*” OR “CO_2 footprint*” OR “carbon dioxide emission*” OR “carbon dioxide footprint*” OR “greenhouse gas emission*” OR “greenhouse gas

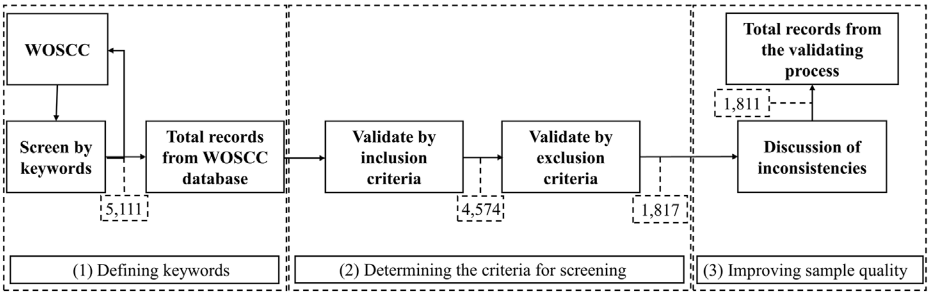

FIGURE 1
The process of data extraction.

TABLE 2 Inclusion and exclusion criteria for screening records.

Inclusion criteria	Exclusion criteria
Keywords present in 'title', 'abstract', and 'keywords'	The literature only mentioned low-carbon, carbon reduction or climate warming but not related to the supply chain research
Publication type was restricted to 'journal articles'	Low-carbon is not a key variable in supply chain research
English language	The literature emphasized on circular economy rather than a low-carbon supply chain
Time: 2003–2021	The literature emphasized sustainable supply chains rather than low-carbon supply chains

footprint*")] AND [TS=("supply chain*" OR "supply network*" OR "value chain*" OR "supply channel*" OR "SC")]. A total of 5,111 records were retrieved using this search string.

Further screening was performed based on time period, research theme, language, and article type. To ensure that the search articles were accurate and comprehensive, we limited the time from 2003 to 2021, and all candidate keywords appearing in the 'title', 'abstract', and 'keywords' were included. The starting point was chosen in 2003, because the earliest government document regarding a 'low-carbon economy' was the British energy-related white paper *'Our Energy Future: Creating a Low-carbon Economy'* in 2003. Then, the publication type was restricted to 'journal articles', as they contained the most reliable knowledge (Caputo et al., 2021), and only the English language was included. A total of 4,574 records related to LCSC remained, yielding a scientific and appropriate database. Next, a thorough screening process was conducted, with two researchers independently reading the articles' metadata, such as title, keyworks and abstract, and filtering relevant articles according to the inclusion and exclusion criteria (Table 2). For articles that were difficult to determine, they then skimmed through the full text to determine whether they were consistent with the topic. More than half of the papers were excluded, either because they were beyond the scope of the current study (for example, only circular and sustainable supply chains were mentioned, without emphasis on carbon emission reduction) or because they had no direct or indirect connection with LCSC (for example, taking carbon emissions as one of the various factors affecting supply chain management). After filtering irrelevant articles, 1,817 articles were left.

Finally, we found slight differences in the documents retrieved by the two authors, and controversial articles were subjected to further discussion until an agreement was reached. Consequently, 1,811 articles remained, which was the final dataset of our analysis.

3 Results

3.1 The characteristics analysis of LCSC research

To gain a more intuitive understanding of the LCSC field, a characteristics analysis -which reveals the current state of knowledge to researchers in a specific field - was conducted. Specifically, we explored the publication trends in this field and analyzed prolific authors, contributing countries, and subject categories.

3.1.1 Publication trends

The number of scientific publications and their growth tendency are important indicators for discipline's

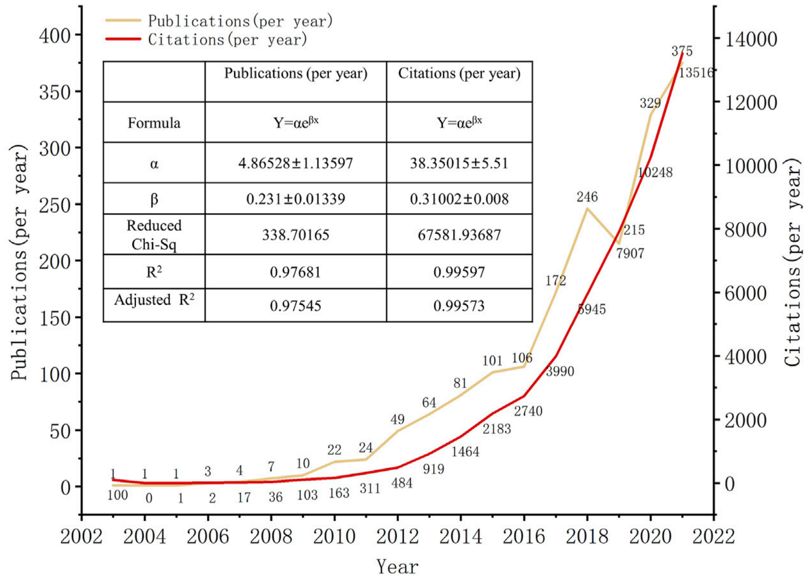

FIGURE 2
Publications and citations over the time horizon.

development. Similarly, to some extent, the scientific impact of an article is determined by the number of citations (Choudhri et al., 2015). Figure 2 presents the growth trajectory of papers and their citations from 2003 to 2021. Before 2009, few papers were published in this field - fewer than 10 per year - indicating little scholarly attention on LCSCs during the early years. Since Meinshausen et al. (2009) proposed GHG emission targets to limit the increase in global warming to 2 °C, the focus on reducing carbon emissions has increased. A continued increase in GHG emissions has intensified or accelerated global warming (Barros et al., 2014). Soon after the United Nations Framework Convention on Climate Change adopted the Paris Agreement in 2015, industries formulated independent emission reduction schemes in various countries. Thus, research on LCSCs has rapidly begun to develop. However, the number of papers published in 2019 was slightly lower than that in 2018, indicating that research concerning carbon management in the supply chain domain was insufficient, although it is a topic worth studying. With carbon emissions in Scope three being larger than those of other commercial activities and many countries gradually joining the ranks of countries actively pursuing carbon peak and neutralization in recent years, academia has refocused on the LCSC-related field.

To better illustrate the characteristics of this trend, we constructed the index growth rate (which can be expressed as Y = $\alpha e^{\beta x}$) to fit the trends of the publications and citations (de Solla Price and Page, 1961), with R^2 equal to 0.97681 and 0.99597, suggesting an exponential growth in publications and citations and the vigorous development of this research field in recent years.

3.1.2 Author analysis

Author analysis supports researchers in finding influential authors in LCSC-related fields who have made a fundamental contribution to this field's development (Merigo and Yang, 2017). Analysis of prolific and influential authors can help researchers quickly grasp the frontiers and dynamic evolution of the field (Cui et al., 2018). Table 3 shows the top 12 productive authors' information following their total publications. *Biswajit, Sarkar*, who specializes in designing sustainable and green supply chains to reduce carbon emissions, produced the highest number of papers on LCSC at 26. He advocated solving the enterprise's optimized inventory management under controllable carbon emission (Mishra et al., 2020; Mishra et al., 2021). *Joseph, Sarkis*, an author ranked fourth, engaged in supplier selection, low-carbon production management, and low-carbon cooperation. Dou et al. (2015) proposed a portfolio evaluation model for environmental supplier development to study supplier performance improvement. More than 40% of them were from China. *Bai, Qingguo* (ranked 2nd) emphasized supply chain coordination with deteriorating items (Bai et al., 2017). *Wang, Chuanxu* (ranked third) and *Yang, Lei* (ranked fifth) contribute to emission reduction from consumers' green preference, the government's low-carbon regulation, and vertical and horizontal cooperation. An h-index, developed by Jorge Hirsch (Hirsch, 2005, 2007), was adopted to evaluate the scholars' scientific

TABLE 3 The most productive authors in the field of LCSC from 2003 to 2021.

Rank	Author (country)	TP	TC	TC/N	H-index
1	Biswajit, Sarkar (South Korea)	26	684	26.31	9
2	Bai, Qingguo (China)	14	512	36.57	9
3	Wang, Chuanxu (China)	14	388	27.71	10
4	Joseph, Sarkis (United States of America)	13	713	54.85	10
5	Yang, Lei (China)	11	302	27.45	8
6	Fabrizio, Bezzo (Italy)	10	279	27.90	7
7	Mir Saman, Pishvaee (Iran)	9	319	35.44	8
8	Nilay, Shah (England)	9	313	34.78	7
9	Kannan, Govindan (Denmark)	8	384	48	6
10	Ali, Diabat (U Arab Emirates)	8	594	74.25	6
11	Chen, Xu (China)	8	304	38	6
12	Guan, Dabo (China)	8	473	59.13	5

TP = Total publications.
TC = Total Citations.
TC/N = (Total Citations/Articles numbers) * 100%.

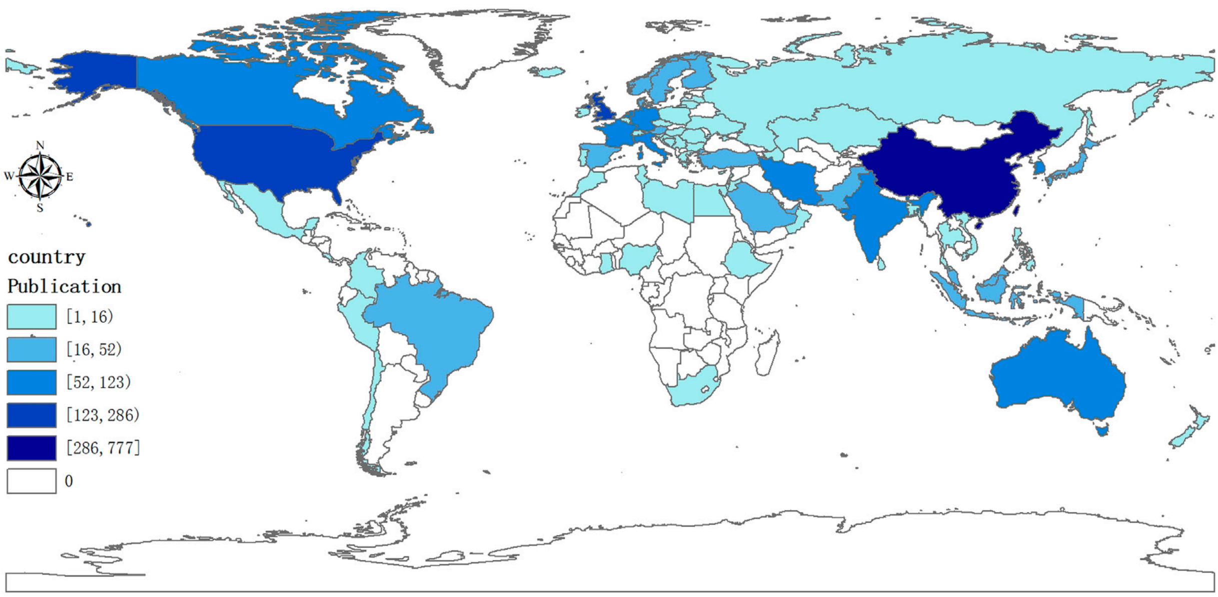

FIGURE 3
Geographical distribution of publications.

output. *Wang, Chuanxu* and, *Joseph, Sarkis* have a high h-index, indicating that these authors have made major contributions to the LCSC field.

3.1.3 Country analysis

A country analysis presents countries' contributions and international cooperation to the LCSC field. Here, we exhibit the main characteristics of the most prolific countries and their international cooperation network. Figure 3 presents the countries that have published papers in LCSC field in recent years, and it uses diverse colors depending on the number of publications. During the 2003–2014 period, the United States appears to have been the most prolific country in the LCSC area (69 papers), followed by the United Kingdom (54 papers) and China (38 papers) (shown in Table 4). However, China overtook the United States 217) during the 2015–2021 period with

TABLE 4 Most productive countries in the field of LCSC.

Rank	Country	TP	TP (%)	2003–2014	2015–2021
1	China	777	42.90	38	739
2	United States	286	15.79	69	217
3	United Kingdom	189	10.44	54	135
4	India	123	6.79	6	117
5	Iran	120	6.63	7	113
6	Germany	84	4.64	16	68
7	Italy	79	4.36	14	65
8	Australia	78	4.31	18	60
9	Canada	77	4.25	14	63
10	Netherlands	60	3.31	16	44
11	France	58	3.20	14	44
12	South Korea	57	3.15	2	55
13	Japan	53	2.93	8	45
14	Malaysia	42	2.32	3	39
15	Sweden	36	1.99	4	32

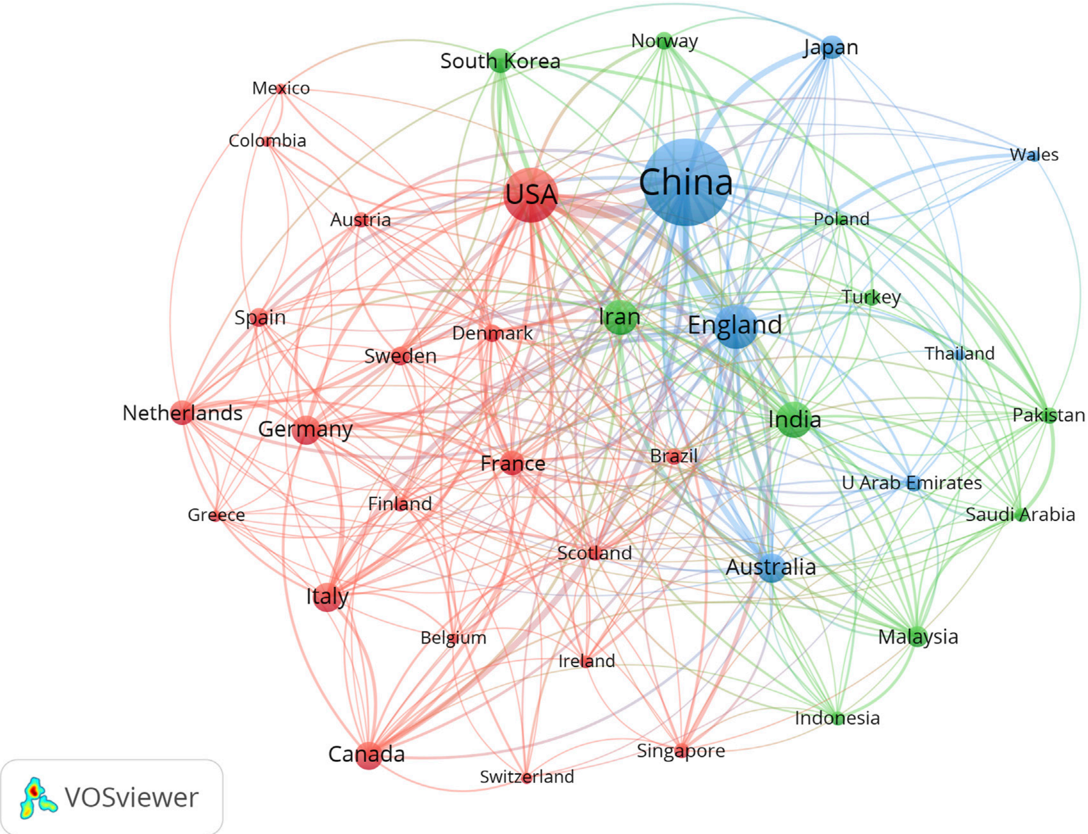

FIGURE 4
The cooperation mapping between main countries based on the co-authorship of papers in the area of LCSC.

TABLE 5 Most relevant Subject category analysis (2003–2021).

Research areas	TP	TP (%)	Research areas	TP	TP (%)
Engineering	869	47.98	Energy Fuels	170	9.39
Environmental Sciences Ecology	762	42.08	Computer Science	149	8.23
Science Technology Other Topics	531	29.32	Mathematics	97	5.36
Operations Research Management Science	324	17.89	Transportation	67	3.70
Business Economics	275	15.18	Public Environmental Occupational Health	33	1.82

739 publications, followed by the United Kingdom with 135. Similarly, several countries such as India and Iran have shown significant growth, indicating that emerging countries have aroused growing interest in the LCSC field. It is not surprising that China has been the most productive country in the LCSC field in recent years. At the end of 2014, China implemented a nationwide carbon emission quota system. From 2015 to 2021, Chinese scholars' research on the LCSC under the carbon quota system accounted for approximately 10% of all published papers.

Figure 4 depicts the cooperation mapping between main countries based on the co-authorship of papers in LCSC domain. The nodes' radius represents the networks' productivity, and the thickness of the connecting lines between nodes indicates the degree of cooperation between countries. Only countries with a joint production of more than 10 are shown in this picture. This result demonstrates the extent of cooperation among main countries in the LCSC domain, with 37 countries forming three cooperation networks. Among them, the red cooperation network is mainly formed by 20 countries, such as the United States, Germany, France, Italy, and Canada, which demonstrates that the LCSC field has a broad base of cooperation among these countries. The green cooperation network is formed by 10 countries such as Iran, and South Korea. China, England, Australia, Japan and several other countries form a blue cooperation network. Although China has the most productivity in this field, its level of cooperation with countries is not yet very high. In addition, there are strong collaborative relationships within individual networks, yet cooperation between different networks is more distant. Therefore, to further promote the development of LCSC area, it is necessary to strengthen the cooperation among countries both in practice and in theory.

3.1.4 Subject category analysis

Subject category analysis helps scholars grasp the subject classification in a field and capture information on interdisciplinary subjects (shown in Table 5). It is worth noting that the articles on LCSC may have interdisciplinary features and potentially belong to multiple research areas; therefore, the total number of publications in the different research fields is larger than the total number of LCSC articles published. In general, the related publications of LCSCs mainly belong to *engineering* (47.98%), *environmental Sciences Ecology* (42.08%), *science Technology* (29.31%), *operation management* (17.89%) and *business economics* (15.18%). Interestingly, LCSC research also involves *energy fuels* (9.39%), *computer science* (8.23%), *mathematics* (5.36%), and *transportation* (3.70%) because of the popularity of alternative fuels, digital transformation, mathematical models, and logistics management in LCSC design.

3.2 The topics and research hotspots of LCSC research

In this section, VOSviewer was used to map the cluster network, which can quickly help researchers identify research hotspots in a specific field. Researchers can get a broad picture of the main research hotspots in a field by using this approach, including its methods, objectives and perspectives (Rejeb et al., 2020). Therefore, the cluster analysis in this article is important to uncover existing themes and connections between themes in the field of LCSC. First, according to the keywords from our final filtered articles, each note was defined systematically by VOSviewer as a noun phrase. In addition, candidate items were automatically labelled by VOSviewer and were manually cleaned by the two authors. In particular, this process has two steps: 1) excluding keywords with no actual meaning (such as 'cities', '0', 'item', 'perspective', 'experience'); 2) merging keywords with the same meaning (such as 'lot-sizing', 'lot-size model'). After fixing the threshold of keyword co-occurrence at a minimum of three, a total of 337 notes were presented in the visualization mapping. Finally, to produce a more reliable and scientific result, we performed an empirical parameter setting with a resolution of 1.15. We then ran the software and obtained five clusters, as shown in Figure 5.

Figure 5 depicts a cluster map of 1,811 articles published from 2003 to 2021, including 337 notes divided into five clusters. The top 15 keywords of each cluster and their frequencies are shown specifically in Table 6. The radius of the nodes reflects the frequency of keywords occurrence, while the thickness of the connecting line in the middle represents the frequency of keywords co-occurrence. Among these nodes, the link between supply chain management and carbon emissions is

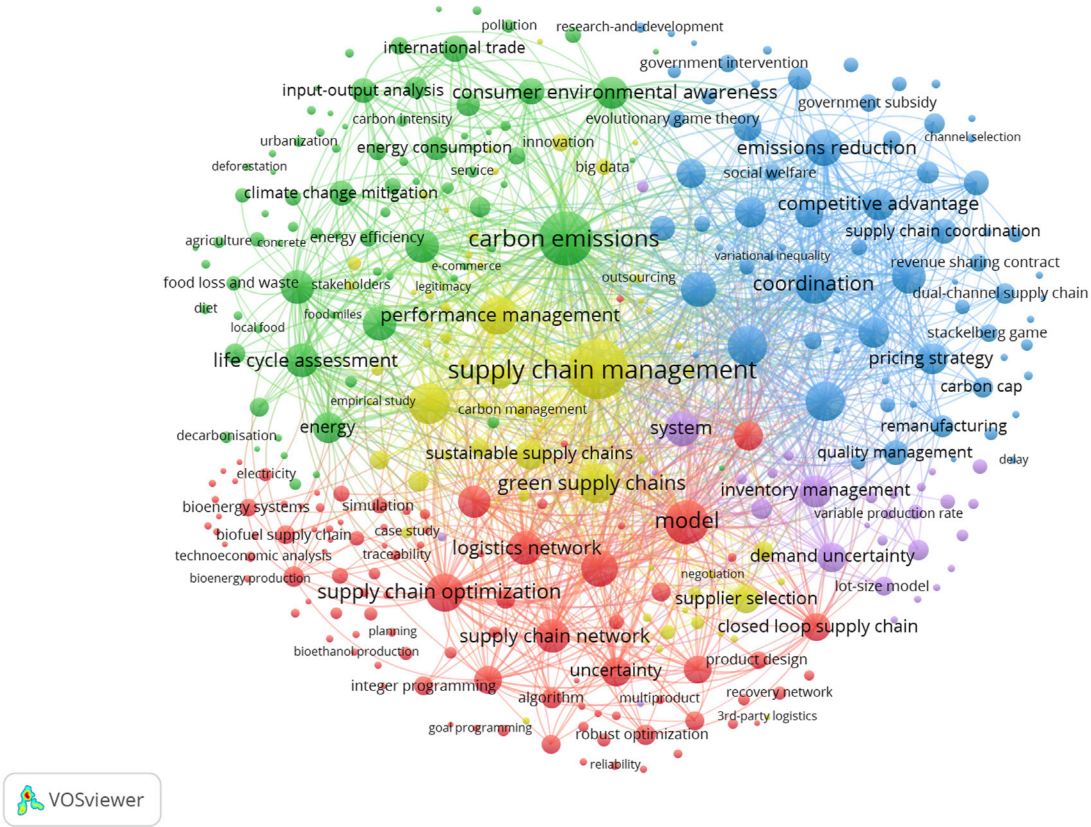

FIGURE 5
The clusters of keywords in LCSC.

TABLE 6 Top 15 keywords and their frequency in each cluster.

Clusters	Keywords (N)
Logistics Management in LCSC	Model (366); Supply chain optimization (256); Supply chain design (218); Supply chain network (185); Logistics network (181); Transportation (156); (Cost-sharing contract (130); (multi-objective optimization (102); Closed loop supply chain (101); Uncertainty (97); Reverse logistics network (94); Biomass supply chain (58); Algorithm (51); Stochastic demand (47); Biofuel supply chain (44); Perishable products (44)
Carbon Accounting in LCSC	Carbon emissions (670); Life cycle assessment (223); Greenhouse gas emission (212); Carbon footprint (205); Environmental management (201); Consumer environmental awareness (163); Energy (147); International trade (105); Input-output analysis (104); Climate change mitigation (98); Economic-growth (73); Energy consumption (73); Global value chain (72); Food supply chain (53); Eco-efficiency (48)
Driving Forces of LCSC	Carbon policy (266); Decision making (258); Coordination (244); Emissions reduction (207); Production system (182); Carbon cap and trade (156); Competitive advantage (142); Strategic analysis (134); Carbon tax (131); Pricing strategy (122); Green technology (115); Low carbon supply chain (104); Game theory (96); Quality management (81); Contract design (75)
Sustainability Management on LCSC	Supply chain management (833); Sustainability (320); Green supply chains (263); Performance management (237); Sustainable supply chains (125); Industry (72); Operations management (52); Order allocation (46); Environmental sustainability (42); Innovation (39); Supply chain integration (37); Big data (28); Analytic hierarchy process (22); Carbon management (20); Fuzzy multi-objective programming (19)
Barriers to LCSC	System (201); Inventory management (149); Demand uncertainty (107); Economic order quantity (46); Risk management (44); Lot-size model (38); Trade credit (22); Imperfect production (21); Deteriorating items (20); Permissible delay (14); Vendor managed inventory (14); Distribution management (9); Imperfect quality (8); Preservation technology (7); Resilience (7)

N=Keyword frequency.

very strong, indicating that many researchers are interested in carbon reduction in the supply chain management process. Moreover, the sub-fields derived from supply chain management, such as green supply chain, sustainable supply chain, and supply chain optimization, have also been widely discussed by scholars. Each cluster has a distinct color and represents a different research topic. These topics reveal the integrated framework of LCSC, which will be analyzed in the next section.

3.2.1 Cluster 1 (red): Logistics management in LCSC

Research in cluster one focuses on understanding logistics design and optimization considering carbon reduction, one of the most critical research topics in the LCSC field. In most studies, scholars' attention ranges from a single logistics cost to combined logistics efficiency and carbon emission reduction (Figueroa et al., 2014; Jin et al., 2017; Mohebalizadehgashti et al., 2020). Many specific studies on logistics design and optimization that jointly consider carbon management have been conducted, including the issues of traffic mode selection, facility location and last-mile delivery (Govindan et al., 2014; Ashtineh and Pishvaee, 2019; Hong et al., 2022).

There is general agreement that a vital factor determining the carbon emissions in logistics is the choice of transportation mode, vehicle selection, and emerging logistics modes. Transportation modes mainly include air, water channels, roads, and rail, each of which has a different rate of CO2 emissions. Light-duty vehicles are responsible for nearly 58% of the emissions. Medium-and heavy-duty trucks account for nearly 24% of CO_2 emissions, whereas freight transportation modes contribute only 10% of CO_2 emissions (Facts, 2021). Thus, the choice of vehicles, especially electric vehicles and alternative fuels, such as biomass fuels, make pivotal contributions to carbon abatement (Karimi et al., 2017; Ashtineh and Pishvaee, 2019; Pozzi et al., 2020). Recently, interest in reverse logistics and green logistics has increased, and several scholars have investigated the effects of these strategies on reducing CO2 emissions concerning the case analysis method (Niwa, 2014; Tacken et al., 2014; Gao, 2019). Others have paid continuous attention to information integration, joint transportation, and vertical and horizontal cooperation in improving logistics efficiency and increasing the carbon emissions reduction rate (Shi et al., 2012; Li H. et al., 2017; Munoz-Villamizar et al., 2021).

Facility location is another determinant of carbon reduction in transportation and logistics systems. The traditional vendor location problem only considers the lowest logistics costs and consumer demand satisfaction. However, under pressure from government carbon-control directives, enterprises must redesign the issues of facility location and introduce carbon reduction into supply chain management. Research on facility location mainly focuses on solution algorithms and model formulations (Klose and Drexl, 2005; Zhao et al., 2018; Kheybari et al., 2019). A multi-objective optimization approach is commonly employed to address this problem in distribution systems (Gong et al., 2017). Moreover, a group of studies investigated routing optimization using mathematical models and big data analysis. For example, Hopkins and Hawking (2018) analyzed the role of big data and the Internet of Things in supporting logistics systems to lower operating costs and reduce carbon emissions.

End distribution, that is, the last-mile delivery problem, is a key obstacle to achieving an efficient and low-carbon logistics system. Brown and Guiffrida (2014) pointed out that e-commerce-based online retailing involving last-mile delivery will likely result in higher carbon emissions. Despite the significant challenge of the last-mile delivery problem, emerging technologies have been applied to address these obstacles. For example, as a low-carbon transportation tool, the drone is commonly employed in this field (Rashidzadeh et al., 2021; Wangsa et al., 2021).

3.2.2 Cluster 2 (green): Carbon accounting in LCSC

Carbon accounting in supply chain measures enterprises' direct and indirect emissions. The carbon footprint is a theme of growing interest in carbon accounting for different application scenarios. On the one hand, with the increasingly serious impact of business activities on global climate change, scholars have begun to evaluate the economic, social, and environmental performance of a product from production, use, recycling, and remanufacturing process, that is, from its whole lifecycle or supply chain. On the other hand, with increasing consumer environmental awareness and low-carbon preferences, there was a rise in voluntary environmental information disclosure to secure more customer loyalty and market competitiveness (Blass and Corbett, 2018). For these two reasons, carbon footprint has been introduced in enterprises for carbon accounting in all business activities. According to the existing research, carbon footprint helps enterprises identify carbon hotspots and supports decision-makers in allocating more carbon reduction efforts to the areas, where such effort is most needed (Acquaye et al., 2011).

Although the carbon footprint is calculated throughout the production life cycle or the whole supply chain, the primary concern of scholars has been transportation, such as the choice of transportation modes and optimal route design (Caracciolo et al., 2018). Moreover, by influencing consumers' low-carbon preferences and purchase intention as well as changing the supply-side production patterns and SC structures, the carbon footprint has been extended to a new field, that is, climate information disclosure - such as carbon labels and carbon footprint certification - to achieve carbon neutrality (Jira and Toffel, 2013; Birkenberg et al., 2021). Furthermore, researchers have conducted extensive footprint studies, such as material, water, and even eco-footprint or environmental footprint.

In general, research on carbon footprints in the existing literature mainly focuses on calculation approaches, labelling (Onozaka et al., 2016) and standardization (Rugani et al., 2013). The most popular topic concerns the methods suitable to evaluate various supply chains. LCA is the most common tool for measuring the environmental impact in the food supply chain, especially in production (Handayani et al., 2021), transportation (Dong and Miller, 2021), packaging (Accorsi et al., 2015; Beitzen-Heineke et al., 2017), storage and retail (Burek and Nutter, 2020), distribution (Wong et al., 2021) and recycling; it supports supply chain managers in determining the optimal scheme for food supply chain management. Recently, food losses and waste evaluation have been emerging topics (Scholz et al., 2015; Cattaneo et al., 2021). In addition to the food supply chain, LCA has been widely applied in the construction, service, power, coal energy and carbon capture-utilization supply chains.

Moreover, any limitations of LCA have been continuously improved, and carbon accounting has been extended to input-output analysis and hybrid LCA. In some cases, the input-output method was applied in disaster recovery (Hata et al., 2021), multi-regional and global supply chains. For example, Liu et al. (2015) applied a multi-regional input-output model to evaluate CO2 emissions embodied in imports and exports. Moreover, the hybrid LCA, such as the Economic Input-Output LCA model, has been used to estimate the carbon footprint in the US manufacturing industry (Egilmez et al., 2017).

3.2.3 Cluster 3 (blue): Driving forces of LCSC

Some scholars have shown great interest in the driving factors that promote the development of LCSCs (Yuan et al., 2019; Li Q. P. et al., 2021; Su et al., 2022). By exploring this cluster's literature in detail, we find that the driving forces for promoting LCSC research mainly include the government, consumers, and intra- or inter- organizations.

The impact of government regulations on supply chain members is discussed intensively in this cluster. Specifically, the carbon tax, carbon cap, carbon cap-and-trade, and carbon offset are the carbon policies of most concern to scholars. Some studies have examined how a single or mixed carbon policy affects all supply chain sectors and how enterprises restructure the supply chain in response to such policy. Among them, research on the impact of these policies on production and transportation (Li J. et al., 2017), channel selection (Kushwaha et al., 2020), supply chain network reconfiguration (Jin et al., 2014) and closed-loop supply chain (Xu et al., 2017) is the most extensive. In addition, the pros and cons of setting rates and the possible negative impacts of various carbon policies have been studied thoroughly (Xu et al., 2021a). Moreover, in addition to government regulation, research on the role of government subsidies in enterprises' low-carbon behavior is gradually increasing. Scholars on this topic firmly believe that appropriate subsidies increase the willingness of firms to invest in green technology to achieve carbon emission reduction (Cao et al., 2017; Li Z. et al., 2021).

Consumers' demand for green and low-carbon products is also a significant driving factor in companies' carbon emission abatement efforts (Liao et al., 2021). On the one hand, consumers' low carbon preference, environmental awareness, price sensitivity, and attitude exert a positive promoting effect on carbon reduction and profits in the supply chain (Ghosh and Shah, 2015; Xia et al., 2018; Xu et al., 2019; Sun et al., 2020; Birkenberg et al., 2021). On the other hand, using carbon labels also reduces the negative impact of information asymmetry, enabling consumers to identify low-carbon products and forcing enterprises to consider emission reduction in supply chain management (Acquaye et al., 2015).

In general, stakeholder collaboration and competition strategies drive LCSC practices. Several scholars have used the evolutionary game method to study the strategies adopted by stakeholders in LCSCs. For example, Yuan et al. (2019) investigated the interplay principles of operational strategies among stakeholders in an LCSC. In addition, the competition strategy and pricing strategy between the upstream and downstream of the supply chain encourage enterprises to compete continuously in the market and promote carbon emission reduction. Enterprises' low-carbon awareness and corporate culture have become key factors in promoting the operation of LCSCs, especially corporate social responsibility (Tidy et al., 2016; Ali et al., 2020; Modak and Kelle, 2021). Owing to this awareness, enterprises are more willing to invest in new technologies, such as blockchain, big data analysis, and cloud computing, to increase the traceability and transparency of the supply chain, increase the trust of consumers, and promote the balance between profits and emission reduction (Singh et al., 2015; Esmat et al., 2021).

3.2.4 Cluster 4 (yellow): Sustainability management on LCSC

Based on the triple bottom line principle, sustainability management in LCSCs is a topic of growing interest. The literature in this cluster can be classified into three dimensions: purchase strategy, innovation management, and coordination.

Supplier selection is an inevitable issue in realizing the sustainable purchase strategy in an LCSC (Beiki et al., 2021). The choice of supplier in the early literature focused on quality, cost, and lead time, while Rao (2002), the pioneer, found that supplier selection played a significant role in making the supply chain green. Indeed, supply chain practitioners have conducted various studies on the choice of green suppliers and performance evaluation, using various methods such as Analytic Hierarchy Process and Technique for Order Preference by similarity to an ideal solution (Azimifard et al., 2018). Similarly, multi-criteria decision-making and performance evaluation are popular in choosing a supplier by considering environmental performance (Pinar et al., 2021), carbon emission (Shaw et al., 2012), information sharing (Li G. et al., 2019), and resilience (Hosseini and Barker, 2016). Moreover, some articles investigate the role of the carbon tax in selecting suppliers through potential cost increases affected by the carbon tax (Choi, 2013; Kondo et al., 2019; Lamba et al., 2019).

The role of innovation in LCSC management is the focus of several studies that highlight the importance of technology, eco-innovation, business models, and collaboration. Some articles present the role of a government policy (e.g., environmental regulation) (Zhang et al., 2020; Deng et al., 2021) and consumers' channel preferences (Xin et al., 2019) in promoting innovative technology. In addition, the perspective of eco-innovation has appeared frequently in LCSC management in recent years. According to de Jesus and Mendonca (2018), eco-innovation is not just green technology but also a strategic promoter of the whole value chain transformation. Finally, innovation plays an important role in the circular development of the LCSC, which also involves collaborative innovation (Hao and Li, 2020) and business model innovation (Hall et al., 2020).

Recently, discussions on supply chain coordination associated with the carbon economy have increased. In general, the literature on this topic has highlighted the role of government policies, consumers' low-carbon preferences and supply chain members' altruistic behaviors in supply chain coordination (Wang et al., 2016; Xu et al., 2018; Fan et al., 2019). Based on these key factors, coordination contracts, such as revenue-sharing contracts, cost-sharing contracts, wholesale prices, quantity discount contracts, and buybacks, have been investigated by decision-makers in recent years (Shen et al., 2017; Taleizadeh et al., 2018; Li T. et al., 2019). Furthermore, compared with a cost-sharing contract, a revenue-sharing contract is the perfect strategy to achieve supply chain coordination (Bai et al., 2019). On the contrary, Peng et al. (2018) point out that a revenue-sharing contract cannot coordinate the LCSC efficiently under yield uncertainty. Moreover, according to Peng et al. (2018), joint emission reduction is regarded as an important strategy for optimizing carbon emissions in LCSCs, in the case of the joint decision of channel selection (Yang et al., 2018) and the firm's green R&D cooperation behaviors (Chen et al., 2019).

3.2.5 Cluster 5 (purple): Barriers to LCSC

Cluster five focuses on barriers to LCSC, which has been widely discussed in the existing literature. Attention to this topic has increased in recent years, emphasizing the transition from barriers within an enterprise to external obstacles (Goh, 2019). The literature reveals two major research issues that have attracted the most interest: one is related to barriers in designing an LCSC, and the other is focused on the opportunity to overcome these barriers.

Barriers to LCSCs are an inevitable topic in supply chain design and have three dimensions: enterprises, consumers, and governments. First, some of the literature in this cluster considers internal barriers, such as the lack of capital or resources, lack of information-sharing between enterprises, and lack of cooperation between supply chain members (Khan et al., 2019). In addition, some uncertainties, such as suppliers' capacities, warehousing capacities, and yield uncertainty, also hinder supply chain optimization (Shaw et al., 2016). Moreover, the research on demand, return, and market uncertainty caused by consumer preferences in recent years has become more popular, mainly focusing on its impact on closed-loop supply chain designs and solutions (Soleimani et al., 2021). Consumers' low-carbon awareness is insufficient, and the application of carbon labels cannot attract their attention. Moreover, uncertainty also appears in government regulations, in the case of implementing the carbon tax rate (Alizadeh et al., 2019), the time lag of the carbon policy (Sun et al., 2020), and the fluctuation of carbon prices under carbon cap-and-trade (Ren et al., 2021), which are also barriers to achieving economic benefits and carbon reduction.

Due to these barriers to LCSCs, some studies provide effective and practical methods to overcome them. Garre et al. (2020) pointed out that data analysis and machine learning accurately predict demand and reduce market uncertainty. Information sharing among supply chain members can reduce the potential risks caused by information asymmetry and GHG emissions and increase supply chain members' profits (Yu and Cao, 2020). Interestingly, some novel supply chain strategies have been implemented to reduce these barriers. For example, Izmirli et al. (2020) proposed an inventory share policy to address demand uncertainty. Moreover, product postponement and vendor-managed inventory practices have improved the supply chain system's flexibility in managing market uncertainty and reducing supply chain emissions (Ugarte et al., 2016).

3.3 Trend topics analysis

In this section, the Bibliometrix R-package was employed to analyze the topic trends in the last 10 years (see Figure 6), which can intuitively reveal the evolution of topics in this field and the current research hotspots. We set the frequency of keywords to five, excluding keywords that appeared less than five times per year. The line's starting point indicates the initial time of the themes, and the endpoint suggests the time the topics disappear. In addition, the circle indicates a sudden surge in the theme at a specific time; the larger the circle, the greater the surge for a brief time. It is worth noting that the

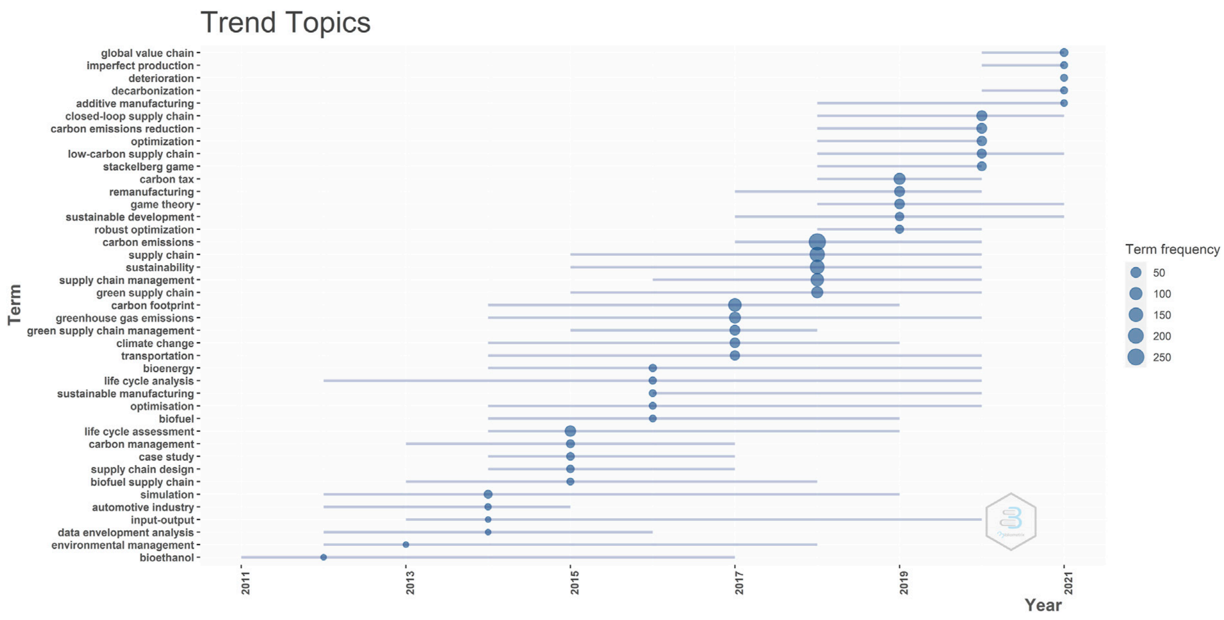

FIGURE 6
The trend topics analysis in authors' keywords.

author's keywords are included in this analysis, while the keywords plus (refers to keywords related to the original article, but the author did not add them) are not included, which accurately reflects the topics that researchers focused on.

LCA appeared earlier than the input-output methods and was widely used in 2015 and 2016. Meanwhile, the input-output method was widely employed in 2014. Carbon accounting has been fully developed in recent years; therefore, we do not find the traces of these keywords in 2021. In addition, over the past 5 years, this research field has focused on green supply chain management, sustainable supply chains, carbon footprints and transportation management. Furthermore, the research direction has gradually shifted to the global value chain, additive manufacturing, deterioration, and decarbonization over the past 2 years.

4 Discussion

4.1 Future research directions

In this section, we discuss the results further and propose future opportunities to address the issues in academic research and the real world. An exhaustive analysis of the research directions for each cluster is presented in the following sections.

Research on Cluster one explored the logistics management in LCSCs, mainly focusing on the choice of transportation mode, facility location, and last-mile delivery. Even though clean transportation is chosen as the primary mode, few articles discuss the application of technology in logistics systems; thus, smart transportation in an LCSC should be highlighted in the future (Sarkar et al., 2019). As for facility location, previous literature has mainly focused on single variables, while future research should consider more complex and integrated models, such as using the location-inventory-routing model for LCSC design (Tavana et al., 2021). In addition, compared with conventional transport, future research on long-distance transport cannot be ignored; the integrated role of cooperation, technology applications, and operational management should form part of the agenda (Robertson et al., 2014). In recent years, COVID-19 has also seriously impacted transportation in LCSCs, especially in terms of the last-mile delivery issues caused by the lockdown. Therefore, it is necessary to comprehensively use artificial intelligence technology and unmanned aerial vehicle to address this challenge and reduce GHG emissions.

According to the existing literature, studies in Cluster two discussed carbon accounting in LCSC, mainly focusing on accounting methods and different application scenarios. However, few studies have analyzed the application of digital technologies such as big data, cloud computing, and blockchain in carbon accounting. Thus, in the future, more attention should be paid to constructing enterprises' carbon emission data platforms to realize carbon transparency and precision by combining them with research on new digital

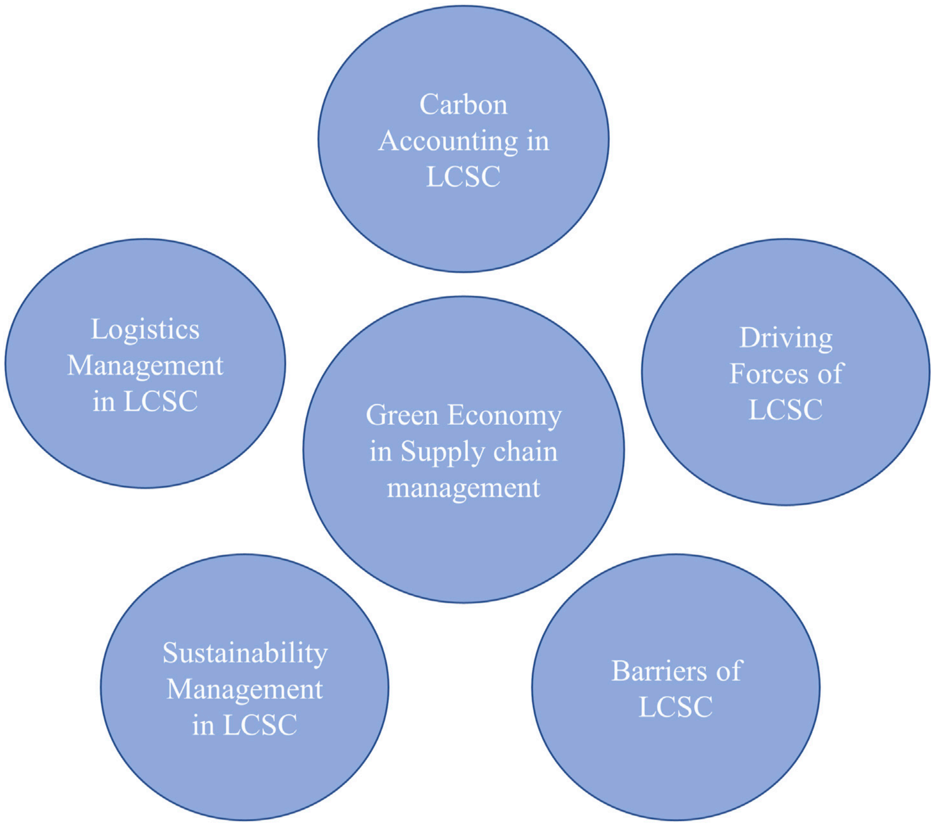

FIGURE 7
Green economy framework in the supply chain.

infrastructure construction and firms' digital transformation (Sun and Zhang, 2020). In addition, carbon certification is important, although little attention has been paid to it by scholars. In the future, more studies on the certification of low-carbon products can be carried out from two perspectives: the consumption subsidy on the demand side and the introduction of third-party evaluation on the supply side. In general, current research uses various methods to calculate the carbon footprint in supply chains, while the linkage effect of core firms tends to be ignored. Hence, studying core enterprises' carbon accounting for upstream and downstream emission reductions is a novel research opportunity. Furthermore, owing to the prevalence of globalization, carbon emissions in industrial transfers are easily ignored, and carbon leakages may occur, which need to be concerned (Zhou B. et al., 2020).

The literature in Cluster three explored the driving forces of LCSCs. However, the current research is largely theoretical, lacking empirical research and data support, which should be strengthened in the future. Similarly, apart from green technology and information asymmetry, a higher number of driving factors should be considered in the future, such as evaluating third-party systems and the green finance of financial institutions. Most importantly, the supply chain structure also affects the implementation of carbon policies; therefore, more attention should be paid to the impact of different driving forces of LCSCs with different energy or market structures.

Cluster 4 (Sustainability Management in LCSC) is a vital topic closely related to external relations; however, it is not fully developed. The existing literature in this cluster mainly investigates purchase strategies, innovation management and coordination among supply chain members. However, according to the results above, most studies focus on coordinating manufacturers and retailers. In the future, more emphasis should be placed on supply chain social responsibility and achieving multiparty coordination by introducing multiple stakeholders (Govindan et al., 2016). Moreover, online-to-offline is a real opportunity, as current attention is paid to reverse logistics and closed-loop supply chain, which are suitable forms of supply chain networks to realize material circulation; by contrast, most literature has ignored the role of information. Thus, developing online-to-offline channels is necessary to achieve information sharing and transparency upstream and downstream of the supply chain, eliminate the carbon footprint, and realize end-to-end sustainable development (Xu et al., 2021b). In particular, the existing research on LCSC information management focuses on the perspectives of technology, theory, and practice.

Articles in Cluster five mainly explored barriers to LCSC, particularly their sources and opportunities. At present, a mixed-linear programming model has been used to evaluate uncertainty; however, it is difficult to describe the real world using this approach. Thus, a nonlinear programming approach is required to describe the complex, changeable, and uncertain real-world situations. To the best of our knowledge, the sources of these barriers are enterprises, consumers, and governments. From a broader perspective, we must further consider supply chain disruption and the increased carbon emissions caused by emergencies such as epidemics and natural disasters. Although a vast amount of literature has introduced stochastic models in recent years, the subject of the analysis is still a simple two-level supply chain structure; however, a complex multi-level supply chain structure should be explored in the future. Moreover, few papers have studied the application of machine learning and data analysis to predict uncertainty in the supply chain, but this topic is worthy of in-depth study. In the future, machine learning, scenario analysis, game theory, and sensitivity analysis can forecast uncertainty and overcome the barriers that the LCSC may face.

4.2 Expansion of the green economy framework

The green economy aims to achieve harmony between the economy, society and the environment (D'Amato et al., 2017), with particular emphasis on efficiency and innovation, as well as the role of non-governmental organizations (Lorek and Spangenberg, 2014). Green economy was first proposed by Pearce et al. (1989) in response to underestimating the current environmental and social costs (Loiseau et al., 2016). After then, it can be defined as low-carbon, resource-efficient and socially inclusive (UNEP, 2011).

However, it is very important to introduce the connotation of green economy into the supply chain management to achieve the innovative, coordinated and sustainable development of all actors in the supply chain. As shown in Figure 7, the connotation of logistics management (low energy consumption, high efficiency, low pollution, low emission) and sustainable management (coordination, innovation, sustainable development) in LCSC is the same as that of green economy (efficiency, innovation). In addition, carbon accounting provides a means for companies to transition to a green economy by making carbon emissions pathways more transparent through carbon footprint and the life cycle assessment. Finally, the barriers and drivers in constructing LCSC are equally important to achieving a green economy, mainly focusing on governments, consumers, businesses, and non-governmental organizations.

5 Conclusion

This paper undertakes a comprehensive study of LCSC domain, highlighting the research status of the five main sub-areas and the upcoming topics concerning LCSC field. We integrated the bibliometric and content analysis methods to support researchers and decision-makers in better understanding this field's development, hotspots, and trend directions and enriching the green economy research framework.

A total of 1,811 articles from 2003 to 2021 were identified, discussed, and analyzed. To answer RQ1, we identified the publication trend, finding that the two key time nodes, 2009 and 2015, were accompanied by a sharp increase in article numbers. *Biswajit, Sarkar*, *Bai, Qingguo* and *Wang, Chuanxu* are the most prolific authors in this field. Moreover, China, the United States, and the United Kingdom have made irreplaceable contributions to this field. Countries should strengthen cooperation based on the co-authorship of papers in this field. Furthermore, this field is interdisciplinary, mainly involving energy, environmental science, science technology, and operations research management.

Concerning RQ2, this paper identifies five clusters: logistics management in LCSC, carbon accounting in LCSC, driving forces of LCSC, sustainability management in LCSC, and barriers to LCSC. These clusters emphasize the significance of logistics and sustainable management in LCSC designs, reveal the practicality of carbon footprint applications, and deeply explore the existing barriers and driving factors. Regarding RQ3, we identified the evolution trends of the important topics in the past 10 years and found that green supply chain management, sustainable supply chain, carbon footprint, and transportation management were hotspots in the last 5 years. Global value chains, additive manufacturing, deterioration, and decarbonization are upcoming topics in the LCSC field. Regarding RQ4, we outlined the current research gaps in each cluster to obtain future research directions. We also proposed the green economy framework in the supply chain to promote better implementation of LCSC.

As implication for theory, we extend the scope of knowledge from LCSC to green economy and construct a green economy framework from supply chain management perspective, which provides new ideas for the development of this field. As implications for practice, we present the authors, national publication performance, current research hot-spots and future research directions in LCSC field for researchers. In addition, advice is provided for supply chain practitioners in logistics management, sustainable development and carbon accounting as well as the opportunities and challenges faced by companies in the process of supply chain emissions reduction.

This study has some limitations. First, the dataset generated in this study was screened according to the inclusion and exclusion criteria by searching the keywords related to this field. Although we attempted to identify all keywords related to this field, we may still have inadvertently missed a few and may not have included all relevant literature. Therefore, selecting the dataset may be biased, even if we have done our best to minimize the potential bias. Moreover, only the WOSCC database was selected for this article, and expanding the scope of the literature may broaden coverage, therefore, multiple data sets should be analyzed in the future to expand coverage.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: Web of Science Core Collection database.

Author contributions

Conceptualization, JL and YB; Methodology, MH; Software, MH; Validation, JL and YB; Formal Analysis, MH; Investigation, YB; Resources, JL; Data Curation, MH; Writing—Original Draft Preparation, MH; Writing—Review and Editing, MH and YB; Visualization, YB; Supervision, JL; Project Administration, YB; Funding Acquisition, JL.

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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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The mediating role of entrepreneurship in the link between high-speed rail and carbon emissions reduction

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Prior studies document that the development of transportation infrastructure, particularly the rapid development of high-speed rail, plays a key role in transforming an economy towards a low-carbon development mode, for example by reducing carbon emissions in China and other countries. However, to date, the mechanisms and paths that link high-speed rail to carbon emission reduction remain ambiguous. The present study seeks to clarify this path by proposing the mediating role of entrepreneurship, arguing that the rapid cycle of people, capital, knowledge, and technology induced by high-speed rail would be integrated by entrepreneurs as new start-ups, leading to industry agglomeration, upgrading, and innovations. These consequences of entrepreneurship would further result in carbon emission reductions. Employing a unique dataset in China, we provide strong evidence for our arguments by setting China's prefecture-level cities as the unit of analysis. The research conclusions are as follows: First, the launch of high-speed rail services has a positive effect on a city's carbon emission reduction. Second, entrepreneurship plays a mediating role in the relationship between high-speed rail and carbon emission reduction. Third, the administrative approval system reform would strengthen the effect of high-speed rail on entrepreneurship. This study therefore clarifies the path through which high-speed rail leads to carbon emission reduction, and reconfirms the role of transportation development in achieving the goal of sustainable development towards carbon neutrality.

KEYWORDS
carbon emission reduction, high-speed rail, entrepreneurship, administration system reform, time-varying DID

1 Introduction

Global warming, which has become a major challenge to sustainable development, is mainly caused by carbon emissions, and has received widespread attention from the international community (Francey et al., 2013; Zhang and Da, 2015). China, as the country with the highest CO_2 emissions, has proposed a series of carbon reduction targets to deal with climate change. For example, at the 75th UN General Assembly in 2020, China unveiled its aim to reach peak CO_2 emissions by 2030 and carbon neutrality by

2060. China's Fifth Plenary Session of the 19th Central Committee held in October 2020 proposed the wide implementation of a green production and lifestyle by 2035, leading to a steady decrease in carbon emissions after reaching the peak. Because low-tech and energy-intensive industries currently contribute to a high proportion of China's development, improving the quality of the ecological environment and reducing carbon emissions remain important tasks for China's economy in the "new normal" phase.

As a low-energy green transportation tool, high-speed rail (HSR) is an important part of the infrastructure to reduce carbon emissions in the transportation industry, and has developed rapidly in recent years. By the end of 2021, the total mileage of China's high-speed railway exceeded 40000 km, and is expected to reach the goal of covering 98% of the urban population of more than half a million cities by 2025. Meanwhile, scholars have also noted that high-speed rail is beneficial to reducing carbon dioxide emissions. In their analysis of the policy of canceling short-medium-haul air routes at the pan-European level, Avogadro et al. (2021) found that about 26.5 million (3.02% of intra-European) offered seats may be cancelled and substituted by high-speed rail, without any significant increase in passengers' travel time. Jia et al. (2021) calculated that every 100 additional HSR trains in a city reduce its total carbon dioxide emissions by 0.14%.

At present, a large number of scholars have discussed the impact of high-speed rail on industrial agglomeration, industrial upgrading, and technological innovation. For example, Murakami and Cervero (2012) and Shao et al. (2017) proposed that knowledge-intensive, time-sensitive, and tourism-based industries that rely on personnel mobility were more susceptible to the impact of high-speed rail, thus producing an agglomeration effect. The research of Lin (2017) and Wang et al. (2019) showed that the operation of HSR can promote the upgrading of industrial structure to service and improve the quality of regional urbanization. Yang et al. (2021) showed that HSR significantly promoted innovation growth and innovation convergence, and the effect values were 14.73% and 5.91%, respectively. Tang et al. (2022) proposed that high-speed rail can significantly increase total factor production efficiency and human capital level. Xiao et al. (2022) indicated that high-speed rail has a robust positive impact on intercity technology transfer through geographical proximity, industrial proximity, innovation proximity, and technology complementarity. Whether high-speed rail will produce economic behavior in the market through industrial agglomeration, industrial upgrading, and technological innovation—thereby reducing urban carbon emissions—is a research topic worthy of discussion.

These effects of high-speed rail have created extensive entrepreneurial opportunities. On the basis of industrial structure upgrading, HSR has a more obvious role in promoting entrepreneurship in the tertiary industry, which will have an impact on the ecological environment. The most intuitive embodiment of eco-environmental quality is the influence on carbon emissions. Zhao et al. (2015) believed that high-speed rail can help optimize industrial structure and produce significant energy conservation and emission reduction effects, while promoting economic growth. Based on the industrial agglomeration effect of high-speed rail, Zhao and Lin (2019) deeply analyzed the nonlinear relationship between industrial agglomeration and energy efficiency based on provincial panel data for the textile industry. Yang et al. (2019) proved that high-speed rail effectively reduced environmental pollution through technical effects, allocation effects, and substitution effects. Among them, technical effects refer to the technological progress brought about by resource sharing; allocation effect represents the resource allocation optimization formed by resource flow; and substitution effect refers to the industrial structure substitution produced by the improvement of resource utilization. Dong X. et al. (2020) showed that high-speed rail can promote optimal resource allocation for productivity in a larger space and improve the human resource level of cities along the line. Wang et al. (2020) and Wang et al. (2022) verified the intermediary role of industrial agglomeration in the relationship between transportation infrastructure and energy efficiency. Huang and Wang (2020) found that high-speed rail was conducive to improving both original and new technology, so as to realize carbon emission reduction and cleaner production by creating a more active innovation and entrepreneurship ecosystem. Dong K. et al. (2020), Ren et al. (2021), and Cheng et al. (2021) tested the impact of natural gas infrastructure, economic growth, and technological innovation on CO_2 emissions. Ma et al. (2021) found that the high-speed rail connection increased the entrepreneurship rate by about 3.5 percentage points. Based on assessment of the economic input-output life cycle, Ren et al. (2022) creatively revealed the negative impact of extreme national climate risk on corporate environmental performance.

In addition, it is worth noting that the implementation of external policies will also have an undeniable impact on the economic effect of high-speed rail. For example, Bruhn (2011) and Branstetter et al. (2014) proposed that loose regulation helped enterprises enter the market and encouraged economic and employment growth. Lee et al. (2011) revealed that the more loose the regulatory measures of enterprise bankruptcy law, the stronger feasibility of enterprises entering the market. Casu et al. (2017) verified that the relaxation of government regulation after the Asian financial crisis had a significant role in promoting the performance of the banking industry. Sun H. et al. (2020) proposed that the strengthening of green financing policy is conducive to increasing the number of environment-driven enterprises and achieving sustainable development. Zhong et al. (2021) empirically determined that the reform of administrative examination and approval system could not only improve the efficiency of industrial resource allocation,

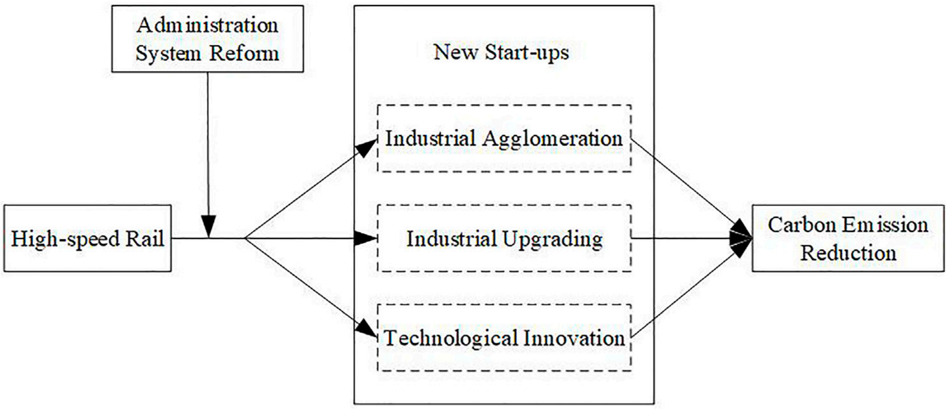

FIGURE 1
The mechanisms between high-speed rail and carbon emission reduction.

but also significantly reduce the degree of productivity dispersion among enterprises in an industry. Sun and Li (2021) showed that the increase in government environmental regulations strengthened the role of high-speed rail in promoting carbon emission reduction. Sun et al. (2022) confirmed that institutional quality has a positive impact on energy efficiency.

The existing literature on the influencing factors of carbon emission mostly focused on the direct impact of industrial structure, urbanization degree, and technical level on the environment, or the comparative study of pollutant emission by various transportation facilities (e.g., high-speed railway and aircraft), in order to highlight the substitution effect of high-speed rail on other types of transportation. Some studies found that high-speed rail can reduce environmental pollution through innovation effect, resource effect, and allocation effect. However, these studies have not paid further attention to which economic activities (e.g., innovation and entrepreneurship) of entrepreneurs will be caused by these effects, and thus influence the ecological environment. In addition, little research has focused on the effect of regional policy on the effect of high-speed rail. Whether the implementation of the policy (e.g., the administrative approval system reform) will further promote the carbon emission reduction effect of high-speed rail has not been verified. This paper applies econometric methods to explore the carbon emission reduction caused by high-speed rail, and further studies whether high-speed rail achieves the effect of reducing energy consumption through entrepreneurial activities. Further, we seek to answer the question of whether there exists a moderating role of administrative system reform between high-speed rail and entrepreneurship.

Since the high-speed railway is regarded as the pilot policy shock, we choose the Difference-in-Differences (DID) method to test the impact of high-speed rail on carbon emission reduction. The research contributions of this paper are mainly reflected in two aspects. First, we construct a theoretical framework of "high-speed rail-entrepreneurship-carbon emission reduction", which opens the "dark box" of the relationship between high-speed rail and carbon emission reduction. This study verifies the mediating role of entrepreneurship in this relationship through three pathways (industrial agglomeration, industrial upgrading, and technological innovation). Thus, the discussion on the internal mechanism of carbon emission reduction has been deepened. Second, this paper introduces administrative approval system reform as a moderating variable, which further enriches the research on contextual factors in the relationship between high-speed rail and entrepreneurship. The results reveal the positive impact of the administrative approval system reform, and expand the direction for future research on how to improve the effectiveness of high-speed rail.

The rest of the article is arranged as follows: the relationship between high-speed rail, entrepreneurship, carbon emissions and administrative approval system reform is discussed in Section 2. The study design (including methods, variables, and data) is introduced in Section 3. The impact of high-speed rail on carbon emissions, the mediating role of entrepreneurship, and the moderating role of administrative approval system reform is outlined in Section 4. Section 5 presents our conclusions and discussions.

2 Theoretical analysis

As an important part of transportation infrastructure, the operating mileage of high-speed rail exceeded 40 thousand kilometers by the end of 2021, ranking first in the world.

Overall, HSR has the advantages of saving travel time and communication costs, enhancing transportation accessibility, and building a resource transfer platform. First, the maximum speed of the high-speed railway has reached 350 km/h, which greatly improves the speed of personnel in different cities, facilitates face-to-face communication between people, and reduces communication costs (Duan et al., 2021). Second, high-speed rail has covered more than 95% of the cities with a population of more than one million, thus expanding the spatial connection scope of cities along the line, and making it possible for people and resources to flow between more cities (Garmendia et al., 2012). Third, the transportation network built by high-speed rail improves the circulation speed of resources between different cities, which effectively increases the density of resources, and is also conducive to alleviating the problem of information asymmetry caused by geographical distance (Graham and Melo, 2011).

It is obvious that with the characteristic of convenience, high-speed rail can improve the flow rate of personnel and information (Zheng and Kahn, 2013), bring benefits of resource reallocation through providing new employment opportunities, and promote knowledge diffusion and knowledge spillover among different cities (Dong X. et al., 2020). The scale and quantity of entrepreneurship, such as the number of start-ups along the line, will have an impact on the local environment. In addition, the reform of the administrative examination and approval system is a breakthrough to straighten out the relationship between the government and enterprises. Because this way of reform emphasizes the decisive role of the market in economic development, it will have an important impact on the relationship between high-speed rail and entrepreneurship. Figure 1 illustrates the theoretical mechanism by which high-speed rail affects carbon emissions, which is mainly reflected in three aspects.

First, the opening of high-speed rail services has accelerated the flow of labor and capital, thereby creating favorable conditions for the expansion of market scale and the formation of industrial agglomeration. On the one hand, high-speed rail has brought about a significant space-time compression effect and increased the spatial connection scope of cities along the line (Elhorst and Oosterhaven, 2008; Guo et al., 2020). The high flow speed and volume of personnel and capital make entrepreneurs willing to pay more attention to the investigation of venture capital in core cities, which effectively alleviates the restriction of geographical distance on venture capital in different places (Ahlfeldt and Feddersen, 2018). On the other hand, high-speed rail promotes the inter-city flow of labor and capital, which is conducive to the central city producing a siphon effect and creating industrial agglomeration to attract high-quality entrepreneurial resources, so as to improve the entrepreneurial activity of the city and cultivate more high-quality entrepreneurial enterprises (Shao et al., 2017; Yang et al., 2021).

Second, high-speed rail makes it easier for production resources to gather in core cities, which promotes the development of their service industry and accelerates their urbanization process, thus affecting industrial upgrading. In the short term, the accessibility of high-speed rail leads to the redistribution of production resources in the market. This feature can reduce service costs and investment costs, and create a better business environment and entrepreneurial opportunities with the demand for high-quality services (Givoni, 2006; Chen and Haynes, 2015). From a long-term perspective, the rapid urbanization of core cities may lead to adverse effects such as high house prices and traffic congestion. At the same time, the development of the core area connected by high-speed rail may widen the economic gap between it and surrounding areas, resulting in the loss of entrepreneurial opportunities in the surrounding cities and a polarization effect between regions (Preston and Wall, 2008; Hall, 2009; Shao et al., 2017).

Third, it can be said that high-speed rail is a platform for the dissemination of explicit or tacit knowledge, which can promote the diffusion and spillover of knowledge among more economic entities and provide new ideas and schemes for technological innovation. In the era of the knowledge economy, complex entrepreneurial activities need to be completed by multiple economic entities to give full play to their competitive advantages. The spatial proximity of high-speed rail makes it easier for economic entities to meet more partners and conduct face-to-face communication, so as to obtain all kinds of spillover knowledge in the process of communication and interaction and form more entrepreneurial choices (Bosquet and Combes, 2017; Claudel et al., 2017). In addition, the knowledge diffusion effect produced by high-speed rail is conducive to enhancing the learning ability and absorption ability of economic subjects, hence deepening the understanding of knowledge and improving their professional level (Carlino and Kerr, 2015; Guo et al., 2015; Dong X. et al., 2020). Therefore, high-speed rail enables economic entities to seek more opportunities for technological innovation across geographical space. Based on the above description, the first three hypotheses are specified as follows:

Hypothesis H1a: High-speed rail has a positive impact on industrial agglomeration of entrepreneurship.

Hypothesis H1b: High-speed rail has a positive impact on industrial upgrading of entrepreneurship.

Hypothesis H1c: High-speed rail has a positive impact on technological innovation of entrepreneurship.

High-speed rail makes it easy to stimulate entrepreneurial behaviors such as industrial agglomeration, industrial upgrading and technological innovation, which will have an impact on carbon emissions of cities along the line. In terms of industrial agglomeration, the time-space convergence and compression effects of high-speed rail accelerate the cross-regional flow of entrepreneurial resources and promote market integration by weakening boundaries and segmentation (Chen, 2012;

Donaldson and Hornbeck, 2016). These are all aimed at optimizing the market resource allocation and energy efficiency, and achieving the effect of energy conservation and emission reduction (Zhang et al., 2020). In terms of industrial upgrading, high-speed rail promotes the spatial aggregation and development of the tertiary industry (i.e., service industry), thus increasing the proportion of entrepreneurs starting businesses in the tertiary industry. Furthermore, it squeezes high-polluting industries and enterprises, making the industrial structure optimized and transformed in the direction of low pollution and high added value (Sun X. et al., 2020; Guo et al., 2021). In the field technological innovation, the gathering of a large number of knowledge-based talents can produce a strong knowledge spillover effect. Resource reconfiguration in this regard guides entrepreneurs to upgrade, promote, and apply green technologies, such as effectively promoting cleaner production and pipeline end treatment, and finally reducing carbon dioxide emissions in the process of entrepreneurship (Andreoni and Levinson, 2001; Yang and Li, 2017). Thus, the second hypothesis to be tested in this study is as follows:

Hypothesis H2: Entrepreneurship plays a mediatorial role in the relationship between high-speed rail and carbon emission reduction.

Moreover, the administrative examination and approval system reflects the regional government's attention to the ecological environment and air quality, as well as the improvement and implementation of regional environmental laws and regulations. Therefore, the reform of the administrative approval system plays a major part in the relationship between high-speed railway implementation and entrepreneurship. On the one hand, the reform of administrative examination and approval system standardizes the government's behavior and allows the decisive role of market resource allocation to be achieved. This enables the resources brought about by high-speed rail to flow from low-efficiency economic subjects to high-efficiency economic subjects, hence providing an institutional guarantee for the improvement of resource allocation efficiency in the process of entrepreneurship (Arnold et al., 2011; Zhong et al., 2021). On the other hand, the reform of administrative examination and approval system reduces the market access requirements for entrepreneurship and strengthens the willingness of entrepreneurs to implement start-up plans and establish new institutions, which also means that high-speed rail generates a stronger impetus for promoting entrepreneurship (Kaplan et al., 2011; Rostam-Afschar, 2014). Foster et al. (2006) suggested that a standardized market competition mechanism is conducive to optimizing the resource allocation mode, so that new enterprises are able to obtain the resources previously held by inefficient enterprises, *via* market selection. Therefore, the third hypothesis to be tested is as follows:

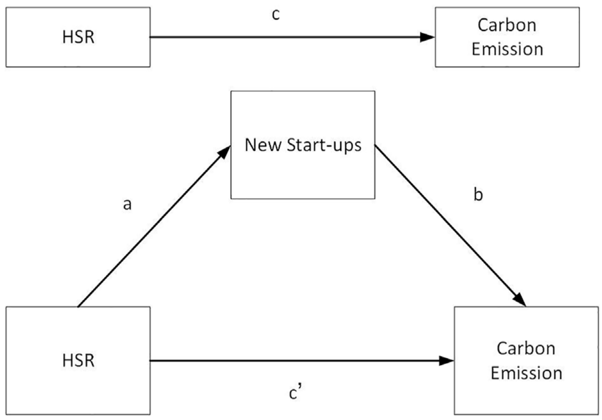

FIGURE 2
The mediating effect of new start-ups.

Hypothesis H3: Administration system reform positively moderates the impact of high-speed rail on entrepreneurship.

To sum up, the impact of high-speed rail on carbon emissions is achieved through the path of entrepreneurship. Therefore, entrepreneurship plays a significant role in the relationship between high-speed rail and carbon emission reduction. Besides, the more efficient the administrative services, the stronger the characteristic effect of high-speed rail. It is evident that the impact of high-speed rail on entrepreneurship will also be affected by the reform system of local administrative examination and approval.

3 Research design

To access the effect of the operation of high-speed rail on carbon emissions, we gather data on the timing of HSR, carbon emission, and other prefecture-level characteristics. This section presents the methodology and variables.

3.1 Methodology

Time-varying difference-in-differences (DID) method is an effective method to test the causal effect (Beck et al., 2010). Time-varying DID is suitable for analysis of HSR operation mainly for two reasons: First, HSR operation is a systematic project from top to bottom, and the opening times of different regions are inconsistent. Therefore, we can identify a control group and a treatment group. Second, we are able to obtain panel data before and after the opening of HSR. Drawing on Beck et al. (2010) and Yang et al. (2019), we use the time-varying DID method to identify the impact of HSR on prefecture-level city's carbon emissions in China. The treatment group is the cities that have opened high-speed rails, and the control group is the cities that never opened high-speed rails during the observation period. The econometric model of the main effect is set as the formula (1).

$$Carbon_{ct} = \partial_0 + \beta_0 HSR_{ct} + \chi_0 Z_{ct} + \delta_c + \varphi_t + \varepsilon_{ct} \quad (1)$$

In Eq. (1), $Carbon_{ct}$ is a measure of carbon emission in prefecture-level city c in year t, $\delta_c$and φ_t are vectors of city and year dummy variables that account for city and year fixed effects, and Z_{ct} is a set of time-varying prefecture-level variables, and $\varepsilon_{ct}$is the error term. The variable of interest is HSR_{ct}, a dummy variable that equals one in the years after city$c$opens the HSR and zero otherwise. The coefficient,β_0, therefore, indicates the impact of HSR on carbon emission. A positive and significantβ_0 suggests that HSR exerts a positive effect on carbon emissions, while a negative and significant β_0 indicates that HSR decreases carbon emissions.

According to theoretical analysis, the operation of high-speed rail is conductive to establishment of new start-ups, and further benefits the city's carbon emission reductions. To test this mechanism, the relationship diagram is shown in Figure 2.

In Figure 2, the first line indicates that the independent variable HSR acts on the dependent variable carbon emission, and the path is c. Because the third variable is not involved, the coefficient c represents the total effect of independent variable on the dependent variable.

The second line indicates after controlling the mediating variable new start-ups, the relationship between the independent variable HSR and dependent variable carbon emission, where the coefficient a represents the effect of independent variable HSR on the mediating variable new start-ups. The coefficient b represents the effect of the mediating variable new start-ups on the dependent variable carbon emission. The coefficient c' represents the effect of independent variable HSR acting on the dependent variable carbon emission after controlling the mediating variable start-up rate, that is, the direct effect of HSR on carbon emission.

Then, the total effect between variables in second line of Figure 2 should be equal to the direct effect plus the indirect effect. That is, total effect = ab + c'. Combining the first line and second line of Figure 2, we get c = ab + c'. C is the total effect, c' is the direct effect, and ab is the mediating effect, also known as the indirect effect. The purpose of the mediating analysis is to test whether the ab effect exists and its proportion in the total effect, reflecting the degree of mediating effect.

We adopt the step-by-step method for testing regression coefficients to judge whether there is a mediating effect, which is divided into three steps (Baron and Kenny, 1986). The econometric model is set as formula (2).

$$\begin{aligned} Carbon_{ct} &= \partial_0 + cHSR_{ct} + \chi Z_{ct} + \delta_c + \varphi_t + \varepsilon_{ct} \\ Med_{ct} &= \partial_1 + aHSR_{ct} + \chi Z_{ct} + \delta_c + \varphi_t + \varepsilon_{ct} \\ Carbon_{ct} &= \partial_2 + c'HSR_{ct} + bMed_{ct} + \chi Z_{ct} + \delta_c + \varphi_t + \varepsilon_{ct} \end{aligned} \quad (2)$$

In formula (2), Med_{ct} represents the mediating variable start-ups, and the definition of other variables is same with eq. (1). In this section, the first step is to test the coefficient c, which represents the total effect of HSR on the carbon emission. The second step is to test the coefficient a, which represents the relationship between HSR and the mediating variable start-ups rate. The third step is to control the mediating variable new start-ups, then test the coefficient c' and b.

In these three regression analyses, the basis for judging whether there is a mediating effect is as follows (Baron and Kenny, 1986; Wen and Ye, 2014). First, the coefficient c is significant, that is, the null hypothesis c = 0 is rejected. Second, the coefficient a is significant, that is, the null hypothesis a = 0 is rejected; and the coefficient b is significant, that is, the null hypothesis b = 0 is rejected. If the above two conditions are met at the same time, the mediating effect is significant. If the coefficient c' is not significant in formula (2) while satisfying the above two conditions, complete mediation occurs.

Furthermore, according to the theoretical analysis, in addition to the mediating effect mechanism, this study also examined the moderating effect mechanism. The econometric model is set as formula (3).

$$Carbon_{ct} = \partial_0 + \beta_0 HSR_{ct}*Mod_{ct} + \beta_1 HSR_{ct} + \beta_2 Mod_{ct} + \chi Z_{ct} + \delta_c + \varphi_t + \varepsilon_{ct} \quad (3)$$

In the formula (3), Mod_{ct}represents the moderating variable administrative approval system reform. The main target of this formula is to determine whether the coefficient of β_0 is significant. The definition of other variables is same with the formula (1).

3.2 Variables

The dependent variable is carbon emission (Carbon). To reduce the problem of heteroscedasticity, this study takes the logarithmic value of the annual carbon dioxide emissions of each city. The carbon dioxide emissions after taking the logarithmic value conform to a normal distribution.

The independent variable of this study is the operation of high-speed rail (HSR). According to the time-varying DID method, if a city has opened high-speed rail in the observation period, 1999–2018, then du = 1, otherwise du = 0. If a city has opened high-speed rail in the observation year or before, then dt = 1, otherwise dt = 0. The value of HSR_{ct} = du*dt.

The mediating variable of this study is the start-up rate (Startups), which is calculated by the value of the number of start-ups to the size of the labor force. In this study, the number of employees in regional units represents the labor force. The moderating variable is the administrative examination and approval system reform (Approve). If a city has reformed the administrative approval system in the observation year or before,

TABLE 1 Definitions of variables.

Variable	Definition
Carbon	Carbon emission, the logarithm value of the annual carbon dioxide emissions of each city.
HSR	The operation of high-speed rail. According to the time-varying DID method, if a city has launched high-speed rail in the observation period, i.e., 1999–2018, then the du = 1, otherwise du = 0. If a city has launched high-speed rail in the observation year or before, then the dt = 1, otherwise dt = 0. The value of HSR_{ct} = du*dt.
Startups	The start-up rate, which is calculated as the value of the number of start-ups to the numbers of labor force.
Approve	The administrative examination and approval system reform. If a city has reformed the administrative approval system in the observation year or before, then Approve = 1, and if there is no administrative approval system reform in the observation year, then Approve = 0.
PerGDP	Per capita of gross domestic product, which is calculated as the value of gross domestic product to the total population of the region for the year.
ThirdGDP	The output value of the tertiary industry accounts for the proportion of GDP, which is measured by the output value of the tertiary industry accounts for the proportion of GDP.
Populationsum	Total population, the logarithm value of total population of the prefecture-level city at the end of the year.
Deposit	The logarithm value of year-end deposit balance of financial institutions in the city.
Studentsrate	Education level, which is measured as the ratio of the number of students in regional colleges and universities to the total population of the region.
Land	The logarithm value of land area in that region.
SecondGDP	The ratio of secondary industry to GDP, which is measured as the ratio of secondary industry output to GDP.

TABLE 2 Descriptive analysis.

Variable	HSR = 0							HSR = 1		
	N	Mean	Std. Dev.	Min	Max	N	Mean	Std. Dev.	Min	Max
Carbon	3,997	2.67	0.77	0.30	5.31	1,122	3.37	0.74	0.38	5.31
PerGDP	3,997	7.32	1.03	1.10	8.39	1,122	7.63	0.85	3.64	8.39
ThirdGDP	3,997	35.81	7.94	9.92	77.54	1,122	42.40	9.93	16.99	77.54
Populationsum	3,997	5.78	0.71	2.78	8.13	1,122	6.05	0.65	3.01	8.13
SecondGDP	3,997	47.33	11.66	15.17	89.34	1,122	47.41	9.32	15.17	73.05
Deposit	3,997	7.43	0.99	1.61	8.43	1,122	7.44	0.98	3.89	8.43
Studentsrate	3,997	0.01	0.01	0.00	0.13	1,122	0.03	0.03	0.00	0.13
Land	3,997	9.37	0.85	5.46	12.44	1,122	9.18	0.73	7.09	12.18
Approve	3,997	−6.02	6.59	−19.00	14.00	1,122	−1.10	3.53	−14.00	19.00
Startups	2,360	1.97	5.18	0.02	83.87	1,244	4.83	8.70	0.09	90.76

then Approve = 1; and if there is no administrative approval system reform in the observation year, then Approve = 0.

The control variables that reflect city's characteristics include: 1) Per capita gross domestic product (PerGDP), which is calculated as the value of gross domestic product to the total population of the region for the year. 2) The output value of the tertiary industry accounts for the proportion of GDP (ThirdGDP), which is measured as the output value of the tertiary industry accounts for the proportion of GDP. 3) Total population (Populationsum), the logarithm value of total population of the prefecture-level city at the end of the year. 4) The logarithm value of year-end deposit balance of financial institutions in the city (Deposit). 5) Education level (Studentsrate), which is measured as the ratio of the number of students in regional colleges and universities to the total population in the region. 6) The logarithm value of land area in that region (Land). 7) The ratio of secondary industry to GDP (SecondGDP), which is measured as the ratio of secondary industry output to GDP. Table 1 shows the definition of all variables.

TABLE 3 Correlation matrix.

	Carbon	HSR	PerGDP	ThirdGDP	Populationsum	SecondGDP	Deposit	Studentsrate	VIF
Carbon	1								
HSR	0.357***	1							1.22
PerGDP	0.053***	0.133***	1						1.04
ThirdGDP	0.211***	0.305***	0.046***	1					2.93
Populationsum	0.535***	0.163***	−0.004	0.140***	1				1.16
SecondGDP	0.262***	0.003	0.015	−0.554***	−0.184***	1			2.27
Deposit	0.056***	0.003	−0.017	−0.037**	0.053***	0.052***	1		1.01
Studentsrate	0.398***	0.340***	0.075***	0.529***	0.093***	0.001	−0.034**	1	1.74
Land	0.165***	−0.098***	−0.019	−0.005	0.294***	−0.303***	0.013	−0.153***	1.32

Note: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

3.3 Data

Data for high-speed railway services are obtained from the Train Schedule Book. Prefecture-level city data are obtained from the China Cities Statistical Yearbook. Information on start-ups comes from the TianYanCha website. After merging these databases and excluding some missing data, this study finally includes 281 prefecture-level cities from 1999 to 2018. Because of the problems of heteroscedasticity and contemporaneous correlation, logarithm form and 1-year lag are taken for some variables in the empirical analysis. Table 2 illustrates the descriptive analysis results.

4 Results

This paper studies the relationship between high-speed rail and carbon emissions. In order to better analyze the relationship between the two, descriptive analysis, correlation analysis, variance inflation factor (VIF) test, parallel trend test, benchmark regression analysis, mediating effect analysis, moderating effect analysis, and robustness test were carried out. The empirical analysis results confirm the research hypothesis. The theoretical analysis and empirical analysis in this paper collectively prove that the launch of high-speed rail services can reduce carbon emissions.

4.1 Correlation test

Table 3 examines the correlation between the indicators selected in this study. The results show that the correlation between the selected indicators is within a reasonable range, and there is no high correlation problem. In addition, this paper also examines the collinearity problem between the indicators. The variance inflation factor (VIF) test results show that the VIF values among the indicators selected in this paper are not high, with an average value of 1.59, and there is no collinearity problem (Katila and Ahuja, 2002).

4.2 Common trend check

The Difference-in-Difference (DID) model is a commonly used measurement tool in the evaluation of policy effects. The underlying principle is to evaluate the changes in the dependent variables in the two scenarios of policy occurrence and non-occurrence based on a counterfactual framework. Accordingly, the sample is divided into an experimental group and a control group. An important premise of using this method is that the samples satisfy "parallel trends"; that is, the two groups of samples must be comparable before a shock or policy occurs, because the control group is assumed to be a counterfactual to the experimental group (Beck et al., 2010; Chen et al., 2021).

We next examine the dynamics of the relationship between high-speed rail and carbon emission. We do this by including a series of dummy variables in the standard regression to trace the year-by-year effects of HSR operation on the logarithm of carbon emission:

$$Carbon_{ct} = \partial + \beta_1 HSR_{ct}^{-8} + \beta_2 HSR_{ct}^{-7} + \cdots + \beta_{18} HSR_{ct}^{+10} + A_c + B_t + \varepsilon_{ct} \quad (4)$$

Where the HSR dummy variables, the HSR_{ct}^{-j} equals one for cities in the jth year before HSR operation, while HSR_{ct}^{+j} equals one for cities in the jth year after HSR operation. Thus, we estimate the dynamic effect of HSR operation on the carbon emission. The vectors of A_c and B_t are vectors of city and year dummy variables, respectively. Figure 3 plots the results and the 95% confidence intervals, which are adjusted for city-level clustering.

Figure 3 illustrates two key points: Carbon emission did not precede HSR operation, and the impact of HSR operation on carbon emission materializes very quickly. As shown, the

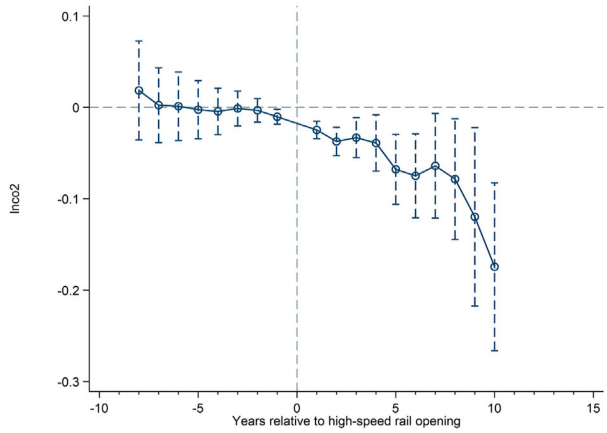

FIGURE 3
The dynamic effect of HSR operation on carbon emission.

TABLE 4 Baseline regression.

Variable	Model1	Model2
	Carbon	Carbon
HSR	−0.027***	−0.017***
	(−5.31)	(−2.96)
PerGDP		0.003
		(1.47)
ThirdGDP		0.007***
		(8.04)
Populationsum		0.036***
		(3.30)
SecondGDP		0.009***
		(13.52)
Deposit		0.003
		(1.32)
Studentsrate		1.074***
		(3.95)
Land		0.045*
		(1.88)
Constant	2.132***	1.086***
	(49.86)	(4.54)
Year	Yes	Yes
N	5119	3600
Wald chi²	72824.06***	28110.10***

Note: z-statistics in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

TABLE 5 The mediating effect of start-ups.

Variable	Model1	Model2	Model3
	Carbon	Startups	Carbon
HSR	−0.017***	0.666**	−0.016***
	(−2.96)	(2.02)	(−2.70)
Start-ups			−0.002*
			(−1.87)
Control	Yes	Yes	Yes
Year	Yes	Yes	Yes
Constant	1.086***	−14.060***	1.352***
	(4.54)	(−3.32)	(5.58)
N	3600	2992	2988
Wald chi²	28110.10***	153.57***	12366.22***

Note: z-statistics in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

coefficients on the HSR dummy variables are insignificantly different from zero for all years before deregulation, with no trends in carbon emission before HSR operation. Next, note that carbon emission decreases immediately after deregulation, such that HSR_{ct}^{+1} is negative and significant at the 5% level. In sum, changes in carbon emission do not precede HSR operation; furthermore, HSR operation has a level effect on carbon emission, but does not have a trend effect.

4.3 Baseline regression

This study explores whether the opening of high-speed rail services will have an impact on carbon emissions. Table 4

TABLE 6 The moderating effect of the reform of administrative examination and approval.

VARIABLES	Model1	Model2
	Startups	Startups
HSR*Approve	0.205***	0.135*
	(3.22)	(1.90)
HSR	0.597*	0.292
	(1.66)	(0.78)
Approve	0.003	0.064
	(0.07)	(1.44)
Control	No	Yes
Year	Yes	Yes
Constant	1.804***	−13.089***
	(4.47)	(−3.07)
N	3606	2992
Wald chi^2	143.25***	161.37***

Note: z-statistics in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

TABLE 7 Robustness check: Baseline regression.

Variable	East		Middle-west	
	Model1	Model2	Model3	Model4
	Carbon	Carbon	Carbon	Carbon
HSR	−0.014**	−0.008*	−0.026***	−0.018**
	(−2.14)	(1.89)	(−3.84)	(−2.14)
Control	No	Yes	No	Yes
Year	Yes	Yes	Yes	Yes
Constant	2.441***	1.704***	1.972***	0.521
	(33.35)	(9.09)	(41.41)	(1.63)
Year	Yes	Yes	Yes	Yes
N	1822	1308	3294	2292
Wald chi^2	41193.13***	47045.27***	48670.64***	15704.67***

Note: z-statistics in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

presents the empirical results of the benchmark regression according to the theoretical assumptions and study design.

Both Model 1 and Model 2 in Table 4 test the relationship between high-speed rail and carbon emissions; however, the difference is that there is no control variable in Model 1, while Model 2 includes all control variables. The results of Model 1 show that the opening of high-speed rail services has a significant inhibitory effect on carbon emissions ($C = -0.027$, $p < 0.01$). The results for Model 2 show that the opening of high-speed rail services can reduce carbon emissions ($C = -0.017$, $p < 0.01$). Therefore, the results of both Model 1 and Model 2 support the hypothesis that HSR operation can reduce carbon emissions.

4.4 Mechanism test: Mediating effect

In order to further verify whether the logic of the main effect is reasonable, this study confirmed the relationship between high-speed rail and carbon emissions by selecting mediator variables and moderator variables. First, according to theoretical analysis, opening of high-speed rail services has promoted the increase of regional start-ups, thereby enhancing regional industrial agglomeration, technological upgrading, etc., and reducing carbon emissions. In order to judge whether the mediating effect mechanism is established, we reference the study of (Baron and Kenny, 1986), using a step-by-step method to test the effect of start-ups. Table 5 shows the result.

Model 1 in Table 5 represents the total effect of HSR on carbon emissions, and its coefficient value represents c. Model 2 represents the effect of high-speed rail on start-ups, and its coefficient value represents a. From the value of a, it can be seen that the opening of high-speed rail services has promoted an increase in start-ups. Model 3 shows the effects of high-speed rail services on start-ups and then on carbon emissions. The coefficient of HSR represents the coefficient value c', which indicates the direct effect of high-speed rail on carbon emissions. The coefficient of start-ups represents the coefficient value b, which represents the effect of start-ups on carbon emissions.

Analysis *via* the step-by-step regression test indicates that start-ups have exerted a partial mediation effect. First, c>c'>0, and c, c' are statistically significant. Second, a and b are statistically significant. The notation of ab is the same as the notation of c'. Therefore, start-ups play a partial mediating role in the effect of high-speed rail services on carbon emissions.

4.5 Mechanism test: Moderating effect

In addition to the mediating effect, this study discusses the moderating effect. We focus on the first half of the mediating effect process—that is, the mediating relationship between high-speed rail and start-ups. In accordance with the theoretical assumptions, this paper selects the reform of administrative examination and approval as a moderating variable; the results are shown in Table 6.

Both Model 1 and Model 2 in Table 6 adjust the relationship between the administrative approval reform on HSR and start-ups. There are no control variables in model 1, and all control variables are included in model 2. It can be seen from Model 1 and Model 2 that the administrative approval reform has played a significant positive moderating effect between HSR and start-ups. This shows that after the opening of the high-speed rail,

TABLE 8 Robustness check: Moderating effect.

Variable	Model1	Model2
	East	Middle-west
	Startups	Startups
HSR*Approve	−0.026	0.248***
	(−0.21)	(2.93)
HSR	1.382**	−0.486
	(2.15)	(−1.06)
Approve	−0.038	0.086*
	(−0.44)	(1.80)
Control	Yes	Yes
Year	Yes	Yes
Constant	−45.675***	3.146
	(−4.79)	(0.73)
N	1078	1914
Wald chi^2	126.23***	120.73***

Note: z-statistics in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1.

TABLE 9 Robustness check: Various samples.

Variables	2005–2018		1998–2015	
	Model1	Model2	Model3	Model4
	Carbon	Carbon	Carbon	Carbon
HSR	−0.018*	−0.015*	−0.021**	−0.014*
	(−1.79)	(−1.75)	(−2.14)	(−1.65)
Constant	2.643***	1.161***	2.643***	1.021**
	(60.41)	(3.15)	(60.41)	(2.51)
N	3707	3056	3132	2778
Adj-R2	0.05	0.26	0.05	0.27

Note: z-statistics in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1.

start-ups can be increased; this effect accelerates even further after the reform of the administrative approval system.

4.6 Further robustness tests

In accordance with previous research design, this study divides China into two parts—the eastern part and the central and western parts, based on the development of each region in China, to further test whether the conclusions of this paper are consistent. The results are shown in Table 7.

Models 1–4 in Table 7 test the relationship between high-speed rail and carbon emissions. Models 1 and 3 do not contain control variables, while models 2 and 4 contain all control variables. Models 1 and 3 examine the relationship between high-speed rail and carbon emissions in the eastern region. The results show that in the eastern region, the opening of high-speed rail can reduce carbon emissions. Models 2 and 4 examine the relationship between high-speed rail and carbon emissions in the central and western regions. The results show that in the central and western regions, the opening of high-speed rail can reduce carbon emissions. Comparing Model 2 and Model 4, it can be found that after the opening of the high-speed rail, carbon emission reduction in the central and western regions is higher than that in the eastern region, which indicates that the opening of the high-speed rail will have a greater impact on the former regions.

This study further verified the relationship between HSR and starts-up for the eastern, central, and western regions. The results are shown in Table 8. Model 1 represents the role of the moderating effect between HSR and starts-up in the eastern region, and Model 2 represents the role of moderating effect between HSR and starts-up in the central and western regions. It can be seen from the results that the moderating effect is more significant in the central and western regions. The reason may be related to the idiosyncrasies of China's economic development: the eastern region has developed faster because of its unique geographical advantages, whereas the development of the central and western regions is relatively slow. Therefore, the reform of administrative examination and approval will play a greater role in regulating starts-up in the central and western regions.

Finally, to further judge the robustness of sample selection, we randomly selected various samples for regression. In Table 9, model 1 and model 2 mainly include data from 2005 to 2018, and model 3 and model 4 mainly include data from 1998 to 2015, to verify the relationship between the opening of high-speed rail and carbon emissions. Its conclusion is consistent with the previous conclusion—that is, there is a negative correlation between high-speed rail and carbon emissions, indicating that the results of this study are robust.

5 Discussion and conclusion

This paper uses panel data for 281 prefecture-level cities from 1999 to 2018 as the research object, and mainly adopts the time-varying DID method to explore the mechanism by which high-speed rail influences carbon emission reduction. This study identifies the influencing relationship between HSR and carbon emission reduction, and verifies the partial mediating role of entrepreneurship between HSR and carbon emission reduction from three perspectives—industrial agglomeration, industrial upgrading, and technological innovation—and reveals the positive moderating effect of administrative approval reform on the relationship between HSR and entrepreneurship. The main conclusions are as follows.

First, high-speed rail plays an important role in urban carbon emission reduction. Following the operation of high-speed railways, carbon emissions have reduced by 1.7%. The result is consistent with Jia et al. (2021). Compared with the east, middle and west areas, the operation of the high-speed railway in the middle and western areas has more influence on carbon emissions (1.8%) than in the eastern area (0.8%). This is because the proportion of secondary industry in the central and western regions is high, and most cities still maintain the extensive growth mode dominated by industry. Therefore, the carbon emission reduction effect of high-speed railways is more significant in these areas. Accordingly, cities in the central and western regions should capitalize on the positive effect of the opening of high-speed rail on industrial transfer and industrial upgrading, and gradually transform the extensive growth mode into a sustainable and high-quality growth mode.

Second, entrepreneurship plays an intermediary role in the relationship between high-speed rail and carbon emission reduction. After the opening of the high-speed railway, a series of economic effects such as industrial agglomeration, industrial upgrading, and technological innovation will stimulate entrepreneurs' entrepreneurial motivation and promote them to carry out green entrepreneurial activities on the basis of optimized industrial structure and at a novel technological level.

Third, after implementation of the high-speed railway, the reform of the administrative examination and approval system has made the growth rate of new enterprises more obvious. China's eastern region has unique geographical advantages and develops rapidly, while the development of the central and western regions is relatively slow. Therefore, the reform of the administrative examination and approval system plays a more significant role in promoting the establishment of enterprises in the central and western regions.

High-speed rail has many positive effects on the economic development of cities along the line. Therefore, full advantage of the trade flow and production resource factor flow brought about by high-speed rail, aimed at increasing the proportion of tertiary industry, promoting green and environmental-friendly entrepreneurial activities in cities along the line, and enhancing the high-quality economic development of these areas (Jia et al., 2017; Qingsong et al., 2018; Li and Cheng, 2022; Yu et al., 2022). However, the government should realize that the positive impact of high-speed rail is not invariable, and negative impacts on economic development may also occur. For example, excessive agglomeration effect will bring development pressure to core cities, resulting in ecological pollution and traffic congestion (Shao et al., 2017). Moreover, the rapid development of core cities will gradually widen the development gap between core cities and remote cities, causing a polarization effect (Albalate and Bel, 2012). In addition, the government should appropriately reform the examination and approval system based on the development of different regions. For example, for the underdeveloped central and western regions, the government should relax the market access system and improve the efficiency of resource allocation in these regions. For the rapidly developing eastern region, the market access threshold can be appropriately raised.

Although the present results provide some theoretical reference for the green and high-quality development of cities along China's high-speed railway, some deficiencies exist. Because of the different opening nodes of high-speed rail in different cities, there are great differences in their operation frequency and time, which will have a heterogeneous impact on the carbon emission intensity of cities along the line. Future research can consider the opening node factors of high-speed railway to verify whether the conclusion is consistent with that of this study.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: China City Statistical Yearbook.

Author contributions

SC is responsible for the original writing, YC is responsible for data, WC is responsible for other works.

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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Higher expected returns for investors in the energy sector in Europe using an ESG strategy

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The energy sector is transforming as new regulations are set in place to take into account the environmental and social factors as well as corporate governance initiatives which can be integrated within organisations. Companies are pushing towards having better environmental, social and governance (ESG) scores as it impacts shareholders, investors, employees, customers amongst many others. The methodology used in this paper is quantitative and includes an analysis of the financial performance of publicly listed companies using return on equity, return on assets, return on sales, return on investment and also used the SARIMA (seasonal autoregressive integrated moving average) model to forecast revenues for the companies included in the research. The aim of this study is to investigate the impact of ESG activities within companies and how it affects investor returns. Considering regional and sectoral effects an observation of a positive relationship between ESG and investor returns is identified.

KEYWORDS

ESG, financial performance, investor returns, energy sector, SRI

1 Introduction

ESG (environmental, social and governance) has now become a global topic of conversation, with organisations all over the world adopting it. ESG is significant because it examines how businesses may meet the requirements of today's generation without endangering the needs of future generations. It also ensures that investors are investing in companies that do not hurt the environment and that pay attention to social issues as well as corporate governance.

Oil and gas firms, like many others in other industries, are increasingly faced with the necessity to meet Environmental, Social, and Governance (""ESG") imperatives in their operations. Traditionally seen as 'licence to operate' issues, these considerations have become increasingly important as corporations face both a rapid energy transition and increased shareholder activism and government oversight. However, while many businesses want to establish their environmental, social, and governance (ESG) credentials, they are impeded by the lack of globally standardised ESG criteria.

Implementing a good ESG strategy is one of the most difficult tasks facing energy firms. Leaders are more likely to achieve outcomes when organisations take a strategic approach to ESG that is tied to the company's goals and values. Because ESG encompasses social and governance activities as well as the environment, oil and gas businesses must analyse their own and their employees' demands. In order to satisfy a variety of stakeholders, an oil and gas company must develop an ESG strategy. ESG programs are also important for promoting energy industry innovation and lowering risks.

With the publication of the UN (ted Nations) Global Compact Initiative's report "Who Cares Wins" in 2004, the term ESG was officially coined (UN, 2004). It set the lofty objective of bringing together three of the most important pillars of ethical finance: environmental, social, and governance. They all deal with different challenges and have a distinct assessment goal. (Billio et al., 2021).

Businesses can develop action plans and measure performance metrics, such as energy diversification, carbon footprint reduction, and natural resource sustainability, using a robust ESG framework. In the energy sector, there is a larger demand for ESG programs than ever before. Embracing ESG demonstrates to oil and gas firms that they care about their employees' well-being. Focusing on ESG is a method for energy companies to demonstrate social responsibility and build confidence, as well as future-proof their operations for the new world of work.

Most firms that have been concentrated on profit maximisation have ignored environmental, social, and governance (ESG) responsibilities for decades. ESG duties were not only seen to have little impact on financial success, but they were also seen as a potential burden on the latter, as they were linked to cost rises. (Billio et al., 2021).

This research paper will discuss the various reasons as to why ESG and financial performance can lead to different conclusions, considering that financial performance can be measured using different methods and different indicators can be used to determine companies' financial performance.

It will also focus on showing the importance of investing in the Social and Governance aspect of ESG as most companies have previously focused mainly on the environmental aspect due to understanding long-term environmental impacts.

It will contribute to society by addressing controversies surrounding the positive or negative correlation between ESG and financial performance that are yet to be resolved. It will also discuss the correlation between operational efficiencies, stock performance and lower cost of capital. It will also show why it is important for businesses to consider how the world is changing and how they can change with it based on what they can do to save the planet and ensure that their companies are run with integrity and are corruption free.

1.1 Background and history

The acronyms CSR and ESG have been used interchangeably in the literature since Carroll (1979) classified corporate social responsibility (CSR) investments into environmental, social, and governance components. The pioneering proposal on ESG and corporate financial performance (CFP), known as trade-off theory, is thought to have originated with neoclassical scholars (Friedman, 1970; Vance, 1975; Wright and Ferris, 1997). They claim that a company's main social obligation is to maximise economic rewards for its shareholders, whereas funds spent on ESG operations increase operating costs unnecessarily, resulting in a drop in profitability (Qureshi et al., 2021).

According to Qureshi et al. (2021), as a result, strong performance on multiple aspects of ESG might have a far broader connotation (Waddock and Graves, 1997) than a cost, a limitation, or a gift from the perspective of strategic management. Furthermore, it has the potential to be a significant source of innovation and competitive advantage (Porter and Kramer, 2006), resulting in enhanced CFP in the future (McGuire et al., 1990). Corporate sustainability is critical for long-term profitability and ensuring that markets give value to all members of society (United Nations Global Compact, 2014).

The benefits of a company's involvement in sustainability are numerous. Employee involvement in the firm and improved motivation (Becchetti et al., 2008), image and brand benefits (Orlitzky and Swanson, 2012), and increased firm competitiveness (Frooman, 1999) are some of them. Kurucz et al. (2008) also mention reduction of costs and legitimacy as other benefits (Ching et al., 2017).

The early research on the advantages of ESG investing was conflicting. Existing research suggests, but does not prove, whether SRI (Socially Responsible Investing) investors are ready to accept substandard financial performance in order to achieve social or ethical goals, according to Renneboog et al. (2008). Investors actively responded to a "shock to the salience of sustainability," according to Hartzmark and Sussman (2019), moving money away from funds featuring low portfolio sustainability ratings and toward those with high ratings. Surprisingly, they found no supporting evidence that high-sustainability funds outperformed low-sustainability funds, bolstering the argument that socially responsible investment has intrinsic (non-monetary) value for investors (Broadstock et al., 2021).

According to a 2006 study by Michael Barnett and Robert Salomon, suggested that the relationship between social and financial performance of specific ESG strategies is arcuate, which implies that as firms increase the concentration of their sustainability efforts, financial performance initially begins to decline before levelling off and improving.

2 Literature review

The early 1970's saw researchers looking for a link between environmental, social, and governance (ESG) principles and corporate financial performance (CFP) (Friede et al., 2015). The environmental, social, and corporate governance performance that is considered in business decision-making is referred to as ESG (Zhao et al., 2018). There have been more indisputable conclusions regarding this association in recent years, although research on this area suffers from nomenclature and terminological discrepancies. According to Meure et al. (2019), there are now thirty three definitions of corporate sustainability in use.

Global warming, deforestation, water and air pollution, land exploitation, and biodiversity loss are all addressed under the environmental pillar. As a result, it assesses a company's energy efficiency, greenhouse gas emissions, waste, water, and resource management activities. As a result, a vast body of research has attempted to define the link between environmental and financial success. According to Derwall et al. (2004), more environmentally responsible companies have higher stock returns than their less environmentally friendly counterparts. Even after multiple methodological checks, these findings are still significant. On the basis of a sample of 2,982 major enterprises from both developed and developing nations, Manrique and Marti-Ballester (2017) reach similar conclusions. (Billio et al., 2021).

The social pillar encompasses issues such as gender policies, human rights protection, labour standards, workplace and product safety, public health, and income distribution, all of which have an impact on employee satisfaction. According to Edmans (2011), there is a strong link between employee satisfaction and long-term stock performance. In the period 1984–2009, American enterprises regarded to offer the greatest working conditions earned a 4-factor alpha of 3.5 percent each year (2.1 percent over the industry standard) (Billio et al., 2021).

Finally, the governance pillar addresses issues such as board of administration independence, shareholder rights, management remuneration, control methods, and anti-competitive practices, as well as legal compliance. Several research, such as Gompers et al. (2003), Tarmuji et al. (2016), and Velte (2017), have emphasised the large favourable influence of these activities (2017). Tarmuji et al. (2016) look at Malaysian and Singaporean firms, Velte (2017) looks at German firms, while Gompers et al. (2003) look at American firms. These three studies show that better governance standards have a favourable impact on a company's profitability. (Billio et al., 2021).

Environmental, Social, and Governance (ESG) reporting is gaining traction among businesses and socially conscious societies. Firms with strong ESG disclosures are thought to have superior operating performance, higher returns, and lower firm-specific risk, according to stakeholders and fund managers. (Shaikh, 2022).

2.1 Theoretical background and hypothesis development

Firms have limited financial resources that must be efficiently distributed across a variety of investment activities (Ahmed et al., 2021). The bidirectional effect of investments in ESG-related initiatives on the corporate financial performance has been well acknowledged in empirical investigations. Nonetheless, the outcomes of these studies (Margolis and Walsh, 2003; Krüger, 2015) that look into the "doing well by doing good" theory are conflicting and inconclusive. ESG performance and CFP have been linked in numerous research in both beneficial and harmful ways. Some researchers found a positive link between environmental performance and CFP (King and Lenox, 2002; Lee et al., 2016; Stanwick and Stanwick, 1998), while others discovered that CSR dimensions of society, environment, and employment practices have a negative impact on CFP (King and Lenox, 2002; Lee et al., 2016; Stanwick and Stanwick, 1998). (Brammer et al., 2006).

Yang et al. (2019) analysed the influence of CSR performance on the financial performance of Chinese pharmaceutical companies from a Chinese perspective. Their findings suggest that a company's total CSR rating has a beneficial impact on financial performance. (Qureshi et al., 2021).

Researchers pointed out the importance of corporate social responsibility (CSR) when it started to be specifically analysed. Corporate social responsibility could be defined as the principles of business ethics to maintain the benefits of all company stakeholders. (Wang et al., 2011).

Regarding the favourable link between sustainability performance and CFP, Kapoor and Sandhu (2010) conducted a content study of Indian companies' annual reports and websites to examine the impact of sustainability on CFP. The authors discovered that sustainability has a considerable impact on return on asset (ROA), return on sales (ROS) and return on equity (ROE), and seems to have a little impact on growth.

The relationship between financial performance and SR reviews was investigated by Akisik and Gal (2014). Sustainability report reviews significantly affect certain short- and long-term financial performance measures (growth associated with ROA, ROS, and ROE, as well as sales), in addition, sustainability reviews have a negative relation with firm value, and finally the effect of sales, leverage, and expansion is moderated by sustainability reviews, according to multivariate analysis.

According to Pan et al. (2014), even while sustainability seems to have no substantial impact on net asset growth or expansion, it may have a favourable impact on firm profits.

Overall, the authors discovered that sustainability had a considerable impact on ROA, ROE, and EPS (Earnings per share). (Ching et al., 2017).

Zhao et al. (2018) examine Chinese listed power generation companies and discover that high ESG performance can boost financial performance. Using MSCI (Morgan Stanley Capital International ESG KLD STATS data from 2000 to 2016, Brogi and Lagasio (2019) show that ESG has a beneficial influence on US company profitability as assessed by ROA, particularly in the banking industry. Ortas et al. (2015) get comparable results for the examples of Spain, France, and Japan, utilising the ASSET4 Database with MSCI data, highlighting the strong positive effect of ESG performance on financial performance for enterprises embracing the United Nations Global Compact (UNGC). The findings of Aureli et al. (2020) for 55 Dow Jones Sustainability World Index listed companies indicate the importance of ESG disclosure on firm market value.

Additionally, Giese et al. (2019), using MSCI ESG data, discovered that ESG information influences not just company valuation but also performance. Reduced capital costs, greater values, higher profitability, and lesser exposure to tail risk are all identified as avenues for such impacts by the authors. Using the Dow Jones Sustainability Asia Pacific Index (DJSIAP) and the FTSE4Good Global 100 Index (FTSE4Good), Lo and Kwan (2017) examine the case of Hong Kong corporations and find weak but encouraging evidence of market responsiveness to ESG information. Furthermore, as compared to SRI, ESG initiatives have a stronger observed effect (Billio et al., 2021).

A. Fatemi et al. (2018) used simulation research to show that CSR has a beneficial impact on corporate value. Similarly, studies showed favourable benefits of brand equity and CSR on company performance using quantile regression (Wang et al., 2015).

Furthermore, Wang and Sarkis (2017) evaluate the aggregate ESG scores of the top 500 green U.S. companies and find that greater CSR governance correlates to improved financial outcomes. However, Ching et al. (2017) discovered no link between a company's sustainability reporting as well as the financial performance of listed companies on the corporate sustainability index.

Achim et al. (2016) looked into a group of companies that were featured on the Bucharest stock exchange. Their findings show a link between both the quality of corporate governance as well as the market value of the companies studied. As a result, a top score on corporate governance indicators can help to maximise the value of a company. Similarly, Wu and Shen (2013) find that CSR rules have a beneficial impact on accounting-based performance proxies.

A greater score on corporate governance and employee dimensions linked to a higher CFP in the banking industry, however product responsibility and society dimensions had no positive influence on CFP (Esteban-Sanchez et al., 2017).

Female corporate leaders are seen as good corporate citizens since they invest significantly more in the environment than their male colleagues (Jiang and Akbar, 2018). (Qureshi et al., 2021).

In order to investigate the neutral impact of sustainability performance on CFP, Inoue and Lee (2011) fragmented sustainability into five aspects and looked at how each of these dimensions influenced financial performance. Employee relations, product quality, community relations, environmental issues, and diversity issues were the five dimensions. ROA and Tobin's Q were used to analyse a company's short-term profitability and the market's prediction of future profitability, with size serving as one of the control factors. The findings imply that the impact of each sustainability factor differs among industries, and that not all five characteristics have good short- and long-term economic implications. (Ching et al., 2017).

Jensen (2002) claimed that managers promoting sustainability will collide with the firm's value maximisation, resulting in a negative correlation across sustainability performance and CFP (Ching et al., 2017).

The influence of ESG upon financial performance is explained by two primary opposing theories. The shareholder and stakeholder value maximisation theories are what they are termed. While the shareholder-focused theory claims that ESG participation is harmful to a company's worth, the stakeholder-focused theory promotes the benefits of ESG practice as a way to increase company value.

The overinvestment hypothesis is based on the premise that there is a negative association between ESG practices and financial performance. According to Barnea and Rubin (2010), the agency problem (i.e., a conflict of interest amongst shareholders and managers) causes managers to invest heavily in ESG at the expense of shareholders in order to benefit themselves (Nguyen et al., 2022).

Such an expenditure goes beyond the threshold where the related expenses appear to outweigh the additional advantages (Krüger, 2015). Empirical support on the costs of ESG financialisation is provided by Liu et al. (2020). When a negative event occurs, such as a product recall, companies with exceptionally high ESG ratings, indicating over-investment in ESG, experience decreased shareholder value (Nguyen et al., 2022). Overall, according to the shareholder-focused view (Brammer et al., 2006; Crisóstomo et al., 2011), implementing ESG reduces corporate value.

The stakeholder-focused theory promotes the benefits of ESG practices, which can help companies perform better financially. The conflict-resolution hypothesis, based on that idea, suggests that implementing ESG could resolve the inherent dispute amongst managers as well as non-investing stakeholders (Freeman, 1984). Enterprises with stakeholder-friendly policies, according to Yarram and Fisher (2021), employ less short-term borrowing, potentially resolving a possible conflict between firms and major stakeholders. According to Cui et al. (2018), higher ESG performance may reduce information asymmetries across firms, resulting in cheaper equity and debt costs (Dhaliwal et al., 2011). (Bhuiyan and Nguyen, 2020).

Gupta and Jham (2021) argue that in the post-crisis phase, companies with superior ESG practices outperform the market. ESG engagement also improves a company's reputation (Branco and Rodrigues, 2006), allowing for greater stakeholder commitment (Arouri et al., 2019), including consumer loyalty (Turker, 2009). This may reduce the volatility of company earnings (Amel-Zadeh and Serafeim, 2018). In essence, the stakeholder-focused thesis states that the higher the firm value, the greater the ESG performance (Lv et al., 2020).

It is worth noting that institutional investors as well as sovereign funds place a high value on ESG performers in order to create long-term financial returns while limiting risk in their investment portfolios (Kapoor, 2017). Conversely, Miralles- Quirós et al. (2019) discovered that Brazilian investors place a high priority on environmental, social, and governance performance. Similarly, Auer and Schuhmacher (2016) investigated the impact of investing in stocks of pro-ESG enterprises on portfolio returns mostly in Asia Pacific, United States and Europe. Similarly, Auer and Schuhmacher (2016) investigated the impact of investing in stocks of pro-ESG enterprises on portfolio returns mostly in Asia Pacific, United States, Europe, and their findings show that ESG-driven investments outperform the market in the United States and Asia Pacific area (Qureshi and Ahsan, 2022).

Friede et al. (2015) did a thorough systematic assessment of the literature and discovered that the association between CPF and ESGP is well-grounded. Almost 90% of the studies observed a non-negative connection, and the vast majority of research showed a favourable CFP-ESG performance relationship. Furthermore, a recent study demonstrated a non-negative relationship between most ESG actions and CFP using a large worldwide data set (Xie et al., 2019).

2.2 Environmental, social and governance ratings and scores

Environmental, Social, and Governance (ESG) reporting is gaining traction among businesses and socially conscious societies. Firms with strong ESG disclosures are thought to have superior higher returns, operating performance, and reduced firm-specific risk, according to stakeholders and fund managers (Shaikh, 2022).

Bloomberg developed and propagated the ESG score, which is a quantitative assessment that covers around 120 environmental, social, and governance factors. In the last three decades, the literature and empirical studies investigating the topic between sustainability disclosure (SD) and financial performance (FP) have expanded at an accelerating rate (Shaikh, 2022).

Environmental, social, and corporate governance (ESG) ratings first appeared in the 1980's as a mechanism for investors to screen companies based on their environmental, social, and corporate governance performance. Eiris (which merged with Vigeo in 2015) was the first ESG rating agency, founded in 1983 in France, while Kinder, Lydenberg & Domini (KLD) was founded seven years later in the United States. (Berg et al., 2022).

ESG ratings: Unlike values-based and positive impact screenings, which look at the products and services a company produces, ESG ratings look at how ESG opportunities and risks are integrated into the organisation's business model. This analysis is usually based on a variety of E, S, and G-related variables, such as carbon footprint, data security, water usage, human capital development, executive pay, and board structure. There are two main approaches to ESG ratings methodologies: one that is based on the rater's subjective standards for what makes "excellent" ESG, and the other that is based on financial relevance. (Giese and Lee, 2018).

ESG rating methodologies:

1. Preference-based ESG ratings: The various ESG indicators are averaged using a scorecard, with the weights representing the preferences, depending on the rater's norms or standards. As it is founded on a weighted aggregate of several various indicators, such as gender diversity and carbon emissions, the concluding ESG score has no clear economic relevance. The scorecard, on the other hand, creates a metric that enables the rater to judge organisations based on this normative scale of "excellent" and "poor" ESG (Giese and Lee, 2018).
2. Financial-model-based ESG ratings: A model that picks and weights ESG variables based on an economic reason and is required to develop ESG ratings that may be used as a financial risk indicator in portfolio construction. MSCI ESG Ratings, for example, convert ESG related risks for a certain industry into a standardised scale. MSCI ESG Research evaluates the extent to which each ESG risk indicator may affect potential income or the company's assets for each ESG risk indicator. Certain scholars have only looked at one facet of ESG (Giese and Lee, 2018).

Considering ESG ratings are a necessary component of most types of sustainable investing, the market for ESG ratings has grown in lockstep with the market for sustainable investing. Several early ESG rating services were bought by prominent financial data suppliers as sustainable investment moved from specialised to mainstream. MSCI purchased KLD in 2010, Morningstar purchased 40% of Sustainalytics in 2017, Moody's acquired Vigeo-Eiris in 2019, and S&P Global purchased RobecoSAM in 2019. (Berg et al., 2022).

It is important to note that it is challenging for investors and consumers to determine which companies are truly committed to sustainability, companies may invest in high - cost sustainability initiatives to reduce ambiguity (Connelly et al., 2011), which is gives reason as to why sustainability reporting frameworks are crucial (Ching et al., 2017).

Investors can use ESG rating agencies to evaluate firms for ESG performance in the same way they can use credit ratings to assess companies for creditworthiness. However, there are a minimum of three key distinctions between ESG and credit ratings. ESG reporting is still in its infancy, while financial reporting standards have evolved and consolidated over the last century. (Berg et al., 2022).

Companies will aim to portray their sustainability attempts and shortcomings in the most favourable light possible, and reporting standards will assist in determining the genuine nature of such initiatives. A consistent framework eliminates the possibility of uncertainty in measuring various types of data (Coalition for Environmentally Responsible Economy, 2010). The implementation of a uniform model for reporting is crucial for investors since it allows them to assess the reports and analyse companies (Ching et al., 2017).

Investors and stakeholders in the energy industry, as well as the public at large, are increasingly aware that ESG ratings are essential drivers. ESG investing was long considered a specialty, but it has now become a critical area for businesses of all sizes, especially after the outbreak of Covid-19.

2.3 Challenges associated with Environmental, social and governance reporting

Different theories have emerged regarding the idea of whether a company is willing to focus on social welfare as an investment. Social welfare can be regarded as environmental and social issues as well as stakeholder value maximisation. Linked to the stakeholder's theory mentioned before by Freeman, an argument has been noted on how in a competitive market, a firm lowering its profits in order to pursue social and environmental goals may not survive the competition and disciplining actions from the market for corporate control (Renneboog et al., 2008).

Conventional financial reporting is regulated, mandated, and must meet the following qualitative criteria: reliability, relevance, materiality, comparability and ability to grasp. ESG reporting, on the other hand, is troublesome due to poor reporting quality that does not match the aforementioned standards. Apart from that, in most parts of the world, ESG reporting is unregulated. As ESG is progressively regarded to be an essential component of effective and sustainable business performance, a global framework is required to provide greater comparability, transparency, avoid fragmentation and reduce the complexity of ESG disclosure, potentially reducing the risk of greenwashing (De Silva Lokuwaduge et al., 2020).

Being a responsible corporate citizen has a cost, as it necessitates corporations actively developing and maintaining their social image, which may yield intangible benefits, whereas ESG initiatives have a measurable cost. Consequently, stakeholders may find evaluating this long-term value offer challenging (Broadstock et al., 2021).

Each provider examines different aspects, employs a different technique, and weights each factor differently (Park and Jang, 2021). Significant disparities in ESG ratings among providers may make ESG management more difficult and limit the influence of ESG scores on investment portfolios (Boffo & Patalano, 2020).

When discussing the wide variance in external assessments, data quality is often brought up. According to Eccles et al. (2019), the market contains about 500 ESG rankings, 120 voluntary ESG disclosure standards and over 100 ESG awards.

One of the difficulties that has surfaced as the need for ESG data develops in tandem with the frequency of responsible investing is the disparity in ESG scores among various organisations. This is hardly surprising, considering the intangible nature of sustainability in general and the inclusion of a variety of subjective scoring criteria (Zumente and Bistrova, 2021).

The challenge of ESG data quality was emphasised by Eccles et al. (2019), who suggested that there is a trade-off regarding reliability and validity of ESG data. Dorfleitner et al. (2015) also found a paucity of ESG rating convergence.

Berg et al. (2022) compared the ESG ratings of five market-leading ESG rating agencies (KLD, Vigeo-Eiris, Sustainalytics, RobecoSAM and Asset4) and found an average correlation coefficient of 0.61, which is significantly lower than the 0.99 correlation coefficient found among commonly compared credit ratings such as S&P and Moody's. The discrepancies were mostly explained by three main factors: firstly, scope divergence, which refers to the different sets of attributes used by each agency, Secondly, weight divergence, which refers to attribute weighting in the calculation of scores, and lastly, measurement divergence, which refers to cases where agencies use different proxies to measure the same attributes (Zumente and Bistrova, 2021).

The source of ESG data may have a substantial impact on the ESG evaluation results (OECD, 2020). Along with the implementation of green strategies, there is also the emergence of greenwashing, which Siano et al. (2017) described as the divergence among two types of behaviour: the first being, minimal eco-efficiency, while the other is, advocacy of the green ideals of sustainable development (Baran et al., 2022).

Greenwashing primarily seeks to promote ecological advantages rather than actual investments in green initiatives, and the majority is used by corporations in the chemical, energy and automobile sectors to promote their own products as ecologically benign (Pimonenko et al., 2020).

2.4 Environmental, social and governance in the energy sector

ESG is not a checkbox exercise anymore, but rather a necessity for retaining and recruiting stakeholder support. The implementation of ESG as a workforce strategy is now more critical than ever. Energy firms that understand the importance of ESG will be equipped to attract and retain the best staff while also satisfying market expectations (Petroplan, 2021).

The oil and gas industry is well-known for posing an environmental danger. Many businesses within this industry have taken initiatives to comply with ESG and reduce their environmental effect. According to sources, the British oil firm BP aims to invest $220 million in solar projects to aid the transition to a low-carbon future. Over the last five years, nearly $60 billion has been invested in renewables, hydrogen, and digital technologies. Environmental conditions are clearly becoming a focus for oil and gas firms in terms of optimising operations and boosting value throughout their enterprises. While most oil and gas corporations will likely continue to invest in traditional production, industry leaders are taking sustainable energy more seriously (Petroplan, 2021).

According to Enverus (2022), the 'Environmental' measure is perhaps the most important for energy companies wanting to present themselves favourably with investors. The elements listed below all have a part in limiting their influence and ensuring that they stay competitive and investable within the market:

1. Greenhouse gas reduction
2. Alleviate greenhouse gases
3. Manage flaring
4. Adhere to new regulations

The table below shows some of the factors that need to be considered within the Energy sector to generate better ESG reports as this shows a level of transparency within the business. This can give confidence to potential investors, customers and stakeholders.

2.5 Environmental, social and governance and investor decisions

The accounting and finance literature has investigated investor decisions centred around information flow to the stock market. Financial reporting's foundations have long been intertwined with financial capital providers' decision-making processes (IASB, 2018). Investors are increasingly interested in non-financial data including Intellectual capital (IC), corporate social responsibility (CSR) and environmental, social, and governance (ESG) (Murray et al., 2006; Zhang et al., 2018).

Prior accounting and finance research has looked at the impact of corporate and government information updates on the stock market (e.g. Bamber, 1986; Graham et al., 2003; Mitchell and Mulherin, 1994). The degree of abnormal returns or trading quantities, which is reflective of the usefulness in the relevant information of the releases, has been used to gauge investor reactions. The degree of activity on the stock market may reveal information about an investor's behaviour (Djajadikerta et al., 2022).

Notwithstanding some mainstream criticism, more than four decades of scholarly and analytical data suggests that incorporating ESG into the investment strategy can result in higher risk-adjusted returns and long-term value creation (Eccles, et al., 2017). Nevertheless, certain managers' and asset owners' long-standing concerns regarding the feasibility of responsible investment methods are not entirely unwarranted. Responsible investing, if not fully applied, can result in inferior financial results. Managers must leverage both ESG opportunities and risks to achieve the full potential of ESG integration. The greatest ESG strategy for this is the full inclusion of ESG considerations into the investment process (Cappucci, 2017).

When making investing decisions, investors employ a variety of ways to get reliable data. Investors used to make judgments only on the basis of financial performance, whereas they now have more objectives than just profit (Park and Oh, 2022). Furthermore, they are making investing decisions based on factors other than just financial data (including ESG data) (Sultana et al., 2018). Corporate CSR actions and management might be influenced by investors (Park and Ghauri, 2015).

Due to the perceived importance of such information to investors' purchase or sell decisions (Holland, 2003), and especially with ethical investors expanding, firms have been interested in the publication of such non-financial information (Tschopp and Huefner, 2015). Regardless, public information like earnings releases, company acquisitions, government laws, and economic policies have been found to have a significant impact on investor decisions, culminating in the degree of activity on financial markets (Djajadikerta et al., 2022).

Asset managers and banks, on the other hand, can encourage businesses to enhance their sustainability standards by requiring a particular level of ESG performance before lending or investing (Zumente and Bistrova, 2021). In this sense, corporations are put under indirect pressure to strengthen their sustainability efforts and, as a result, their financial resilience (OECD, 2020).

Asset owners have a considerable influence since they can require that a particular level of ESG criteria and disclosures be met throughout their portfolio (Eurosif, 2016). According to an S&P poll of 194 credit risk experts working in banks and other financial institutions, 86 percent of respondents believe that rising investor demand is driving the integration of ESG factors into credit risk assessments. 83 percent of those polled agree that environmental, social, and governance (ESG) factors play an important role in credit risk assessment (S&P Global Market Intelligence, 2020; Zumente and Bistrova, 2021).

Socially responsible investors value not only the financial return on their investments, but also the societal impact. These preferences for return, risk, and social responsibility can be implemented in a variety of ways, and numerous multi-criteria portfolio optimization models have been developed to fill this gap over time (Amon et al., 2021).

Park and Oh (2022), state that individual investors are becoming more interested in ESG investing for two reasons.

ESG investing, for starters, aggressively advocates ethical investment practices; secondly, ESG investments are seen as a way to improve the performance of managed portfolios, as well as a way to boost returns and lower portfolio risk (Broadstock et al., 2021). A business announcement is important public information that assists individual investors in making informed investment decisions quickly and effectively (Pradhan and Kasilingam, 2015).

According to Zumente and Bistrova (2021), due to the long-term and active interaction that exists between financial investors and enterprises, private equity and venture capital firms are uniquely qualified to integrate and develop ESG standards in their portfolio firms (Invest Europe, 2021).

Due to the modern portfolio concept, any approach that restricts a portfolio's investment tends to force the manager to select from a smaller range of prospective investments, reducing the portfolio's potential to diversify firm-specific risk and, ultimately, the portfolio's long-term potential return (Asness et al., 2018; Cappucci, 2017).

Scholars have been interested about price and stock market changes that are not explained by basic study. Changes in investor views are thought to produce price swings and large fluctuations in trading volume on the stock market. Changes in investor beliefs, on the other hand, may be influenced by emerging information, which, when perceived by investors, might have an impact on their actions (Djajadikerta et al., 2022).

Several worldwide and regional research allow financial investors to determine their present level of ESG compliance. According to an EY global institutional investor survey, 98 percent of institutional investors use ESG variables to evaluate company performance, with 72 percent utilising a methodical approach, up from 32 percent the previous year. Furthermore, 43 percent of respondents stated that the company's non-financial performance has played a significant impact in investment decision-making in 2019 (EY, 2020).

Bilbao-Terol and colleagues (2019), introduce a goal-programming approach for an SRI portfolio, for example, that allows investors to align their ethical and financial inclinations. They show that investors' risk attitudes influence the loss of return as a result of picking SRIs using UK mutual funds (Amon et al., 2021).

3 Data and methods

Clark et al. (2015), presented an upgraded meta-study, which drew on more than 200 sources, found a striking link between rigorous sustainable corporate practices and economic performance. In fact, 45 of the 51 academic works analysed (88 percent) reveal a link between sustainability and operational effectiveness. Eccles et al., 2014) found that the portfolio of strong sustainable companies beats the portfolio of low-sustainability companies in terms of stock market and financial performance from 1993 to 2010. These findings support theoretical predictions of a null to mildly positive relationship between ESG and CFP (Baran et al., 2022).

In this study, the author adds ongoing debate on whether a company's ESG performance affects its CFP by posing the following research question: Do investors investing in the European energy sector, using an ESG strategy, have expected higher returns?

To answer that question, The paper investigates at whether there is a link between ESG performance and CFP, by relying on a quantitative method conducting the following accounting-based profitability measurements as a proxy: return on equity (ROE), return on investment (ROI), return on assets (ROA), as well as return on sales (ROS). The fact that most of those ratios have appeared in earlier research projects on the relationship between ESG performance and CFP, as analysed in the meta-analysis by Margolis et al. (2009), justifies such a choice.

3.1 Return on equity

Return on equity (ROE) is a ratio that measures a company's ability to generate net income dependent on individual equity; it is an indicator of profitability from the standpoint of the shareholders. The higher the company's ROE, the greater its ability to earn more profits, and consequently higher stock prices (Nursiam and Rahayu, 2019).

A high ROE indicates that the company has done a good job investing its capital to generate returns for its shareholders. As a result, the relationship among ROE and stock price can be considered positive. Hutami (2012), Rosmiati (2016), and Sutapa (2018) all believe that ROE has a favourable and considerable impact on stock prices (Nursiam and Rahayu, 2019).

ROE is a ratio used to determine a company's ability to generate net income based on a specific capital share; it is one of the profitability assessments from the shareholders' perspective. The formula for the ROE variable is as follows, according to Mardiyanto (2009):

$$\text{ROE} = \text{Net Income after Tax/Shareholers equity}$$

An advantage of using ROE is that it compares companies across different industries by concentrating on their capacity to yield money to shareholders. Revenue and profit margins differ substantially between industries, making comparison challenging. However, ROE transforms profits data into a highly meaningful metric that can be evaluated across industries.

In hindsight a significant issue with return on equity is that it does not account for a firm's debt. It simply takes into account net income and shareholder equity. As a result, a firm can have large amounts of unsustainable debt and still appear to be doing well based on the return on equity metric.

3.2 ROA

Return on assets is a measure that shows how profitable a company is in comparison to its total assets. A higher return on investment (ROI) implies that a corporation is more effective and productive in maintaining its balance sheet to create profit, whilst a lower ROA suggests that there is space for development. ROA can be used by investors to measure how well a company utilises its assets to make a profit. ROA can be calculate using the following formula:

$$\text{ROA} = \text{Net Income}/\text{Total assets}$$

A possible benefit of using ROA is that because it is based on operational income, the indicator accurately reflects the impact of both equity as well as loan financing on asset expenditures and their potential to create profit. As a result, organisations with various financing arrangements can be evaluated without any modifications.

It can be mentioned that one of the major issues with return on assets is that it does not account for intangible assets. Numerous businesses in the current economy depend significantly on intangible assets to deliver significant value. Therefore if it is considered, it may not be awarded the right value while recorded for in assets suggesting that one could wind up undervaluing a business and thus making a terrible investment decision.

3.3 Return on sales

Return on sales (ROS) is a metric that measures how effectively a company converts sales into profits. An increasing ROS suggests that a company's efficiency is improving, whereas a declining ROS may indicate imminent financial difficulties.

This efficiency ratio is used by creditors, investors and other debt holders because it effectively communicates the proportion of operational cash a firm produces on its sales and provides insight into future dividends, the company's capability to repay debt as well as reinvestment potential. ROS can be calculated using the formula below:

$$\text{ROS} = \text{Operating profit}/\text{Net sales}$$

Data from ROS can be contrasted to statistics from a trend analysis to indicate the company's progress over time. If a company's return on sales has gone up, then they have improved financially, and if it has declined, it might assist them to realise where they need to improve. One can also conduct a comparative examination of other firms to see if they are ahead of their competitors, however the review is more successful if it involves a firm within the same sector.

However, it is not an appropriate representation of returns because it is suggested that a corporation should assess the worth of its returns using capital rather than sales. In addition companies that are just starting out would not have sufficient data to calculate ROS as they also have high operational expenses.

3.4 Return on Investment

Return on Investment (ROI) is a prominent profit indicator that is used to assess how well an investment has done. When considering whether or not to or not to invest in the purchase of a firm, it can be used to calculate the profitability of a stock investment. ROI is a defined, generic measure of profitability since it is reasonably simple to compute and understand (Bodie,Z, & Kane,A, 2020). ROI can be calculated using many formulas, however the following formula is the one used in this paper:

$$\text{ROI} = (\text{Net income}/\text{cost of investment}) \times 100$$

ROI assists managers in assessing the rate of return that may be expected from numerous investments in several areas. This enables them to make an investment that will boost departmental as well as organisational performance. Also, while making the best use of existing investments.

Furthermore, a downside of ROI is it does not take into account the period in which an investment is actually held. Thus, a profitability metric that takes into account the holding duration may be more beneficial for an investor comparing potential investments.

3.5 Environmental, social and governance risk rating scale

This scale is a digest of sustainalytics ESG risk ratings. Sustainalytics' ESG Risk Ratings assess a company's susceptibility to industry-specific material ESG risks and how well those risks are managed. This multidimensional approach to quantifying ESG risk combines management and exposure ideas to result in an unbiased assessment of ESG risk. It establishes five levels of ESG risk complexity that may have an influence on a company's enterprise value (Sustainalytics, 2022).

Lower ratings imply reduced unmanaged ESG risk, whereas higher scores represent more unmanaged risk. Unmanaged Risk is calculated on an open-ended scale with a zero (no risk) beginning point and, in 95 percent of instances, a maximum score of less than 50. Companies are classified into one of five risk categories mentioned in the table above, based on their quantitative scores. (Sustainalytics, 2019).

Since these risk classifications are absolute, a 'high risk' evaluation indicates a comparable level of mismanaged ESG risk throughout all sub industries covered. This means that a company in one sector can successfully be compared to another in a completely different sector. With the success of ESG Risk Rating Scores it has developed a unified currency for ESG risk (Sustainalytics, 2019).

Within the ESG Risk Ratings, an issue is considered relevant if its existence or omission in financial reporting is anticipated to affect the judgments of a reasonable investor. To be deemed essential in the ESG Risk Ratings, a concern must have a relatively significant implication on a company's economic value and, as a result, its financial risk- and return profile from an investment standpoint (Sustainalytics, 2019).

It is important to note that an underlying concept of the ESG Risk Ratings is that the globe is shifting to a much more sustainable economy and that, as a result, proper management of ESG risks should be correlated with superior long-term organisational value. Several concerns are substantial from an ESG standpoint even though the financial effects are not completely quantifiable currently (Sustainalytics, 2019).

There are 3 building blocks considered when it comes to a company's overall rating score.

The first is Corporate governance which accounts for approximately 20% of a company's total unmanaged risk score. It relates to the policies and procedures that govern and control business operations which can include business ethics and risk management, among others. (Standard Chartered, 2021). This is an important building block as it helps mitigate risks such as money laundering, fraud scandals, corruption and many others.

The second building block is material issues. Material ESG concerns are those that have an influence on a company's financial risk-return profile. Within this building block, issues surrounding the environment, human capital management and health and safety are incorporated. It can be mentioned that in fact not all ESG issues are correlated with financial performance and this may be different from one industry to the other, however recognizing major ESG concerns is critical for investors as companies are subject to various ESG challenges with varying degrees. (Standard Chartered, 2021).

The third and final building block is Idiosyncratic ESG Issues. These issues are unforeseeable and therefore they might happen to any company in any sector and hence fall beyond the logic that captures sub industry-specific material ESG problems. If the corresponding incident assessment by Sustainalytics is deemed high and severe, idiosyncratic issues become major ESG issues. This encompasses important anti-competitive activities as well as social supply chain mishaps (Standard Chartered, 2021).

3.6 SARIMA

SARIMA stands for Seasonal AutoRegressive Integrated Moving Average. The SARIMA model augments an ARIMA model by accounting for seasonality. It is a major statistical model proposed by Box and Jenkins around the 1970's (Shumway and Stoffer, 2017).

SARIMA's multiplicative process will be represented as (p,d,q) (P,D,Q)s with p denoting non-seasonal AR order, d denoting non-seasonal differencing, q representing non-seasonal MA order, P denoting seasonal AR order, D signalling seasonal differencing, Q representing seasonal MA order, and s denoting time span of recurring seasonal pattern (Arzo Ahmed and Moloy, 2018).

ARIMA is a popular method for identifying patterns in non-stationary time series (Shumway and Stoffer, 2017). Some periodical time series are primarily employed with the ARIMA model, namely the non-seasonal ARIMA (p, d, q) model. The duration of the seasonal period is shown by the subscripted letters'. For example, s = 7 in an hourly data time series, 4 in a quarterly data series, and 12 in a monthly data series (Permanasari et al., 2013).

The ARIMA model is illustrated as:

$$z_t = \delta + \phi_1 z_{t-1} + \phi_2 z_{t-2} + \cdots + \phi_p z_{t-p} + a_t - \theta_1 a_{t-1} - \theta_2 a_{t-2} - \cdots - \theta_q a^{+}_{t-q}$$

When z_t is the level of differencing, the constant is denoted by δ, and φ is an autoregressive operator, a stochastic shock corresponding to time period t, and θ is a moving average operator.

The model could be described more explicitly without differencing procedures as:

$$(\Phi(BS)\varphi(B)(xt-\mu)) = \Theta(BS)\theta(B)wt$$

The non-seasonal components are:

$$\text{AR: } \varphi(B) = 1 - \varphi 1B - \cdots - \varphi pBp$$
$$\text{MA: } \theta(B) = 1 + \theta 1B + \cdots + \theta qBq$$

It is worth noting that the seasonal and non-seasonal AR components multiply each other on the left side of the formula, while the seasonal and non-seasonal MA elements multiply each other on the right side of the formula.

As seen in an example given by Murat and Adanacioglu and Yercan (2012): Assume we specify ARIMA (0, 0, 1) (0, 0, 1)12 for the analysed series.

The model incorporates a non-seasonal MA (1) component, a seasonal MA (1) component, with no differencing, and no AR components, with S = 12 as the seasonal period.

The non-seasonal MA (1) polynomial can be given by: (B) = $1 + \theta_1 B$.

The seasonal MA (1) polynomial is expressed as: $\Theta(B_{12}) = 1 + \Theta_1 B^{12}$.

The model can be written as follows: $(x_t - \mu) = (1 + \Theta_1(B^{12}))(1 + \theta_1(B))w_t$.

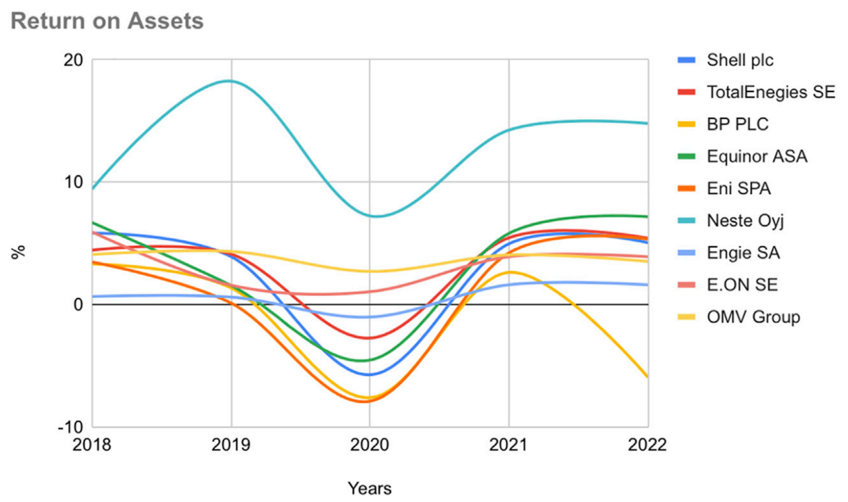

FIGURE 1
Line chart: Return on equity. Source: Own elaboration.

After multiplying both polynomials on the right side, we get the following equation

$$(x_t - \mu) = (1 + \theta_1 (B) + \Theta_1 B^{12} + \theta_1 \Theta_1 B^{13}) w_t$$

Which can also be written as

$$= w_t + \theta_1 w_{t-1} + \Theta_1 w_{t-12} + \theta_1 \Theta_1 w_{t-13}.$$

Therefore we can conclude that the MA components in this model lags at 1, 12 and 13.

George Box and Gwilym Jenkins investigated a streamlined method for acquiring extensive information about the ARIMA model and employing the multivariate ARIMA model. The Box-Jenkins (BJ) approach comprises of four successive phases:

1. Identification: This stage is concerned with the selection of the order of regular differencing (d), seasonal differencing (D), non-seasonal order of Autoregressive (p), seasonal order of Autoregressive (P), non-seasonal order of Moving Average (q), and non-seasonal order of Autoregressive (P) (Q).
2. Estimation: The previous data is utilised to determine the variables of the preliminary model.
3. Diagnostic checking:The diagnostic test is done to ensure that the preliminary model is suitable.
4. Forecasting: Step 3's final model is utilised to predict forecast values.

To investigate the SARIMA model this approach is commonly used because of its capacity to capture the relevant trend by evaluating historical patterns (Permanasari et al., 2013).

Seasonal Autoregressive Integrated Moving Average, SARIMA supports univariate time series data with a seasonal component which is the nature of the study here. To investigate the SARIMA model this approach is commonly used because of its capacity to capture the relevant trend by evaluating historical patterns (Permanasari et al., 2013).

The SARIMA method is one of the modelling approaches in forecasting in this industry. Several studies have applied this method (Malik and Yadav, 2020) to forecast ESG and performance based on transformation of data (Ding et al., 2010) By using Root-Mean-Square Error, the authors found that Seasonal Autoregressive Integrated Average (SARIMA) gave the most accurate results for the classical approach used in this paper in forecasting returns in the energy sector using the ESG scores (Gao et al., 2022).

3.7 Data

This chapter will go through the data in greater detail, information about the firms included in this paper, as well as some summary statistics.

The data used in this study to calculate ROA, ROE, ROS, and ROI have been obtained from published financial statements from the companies included and use a time frame from 2018 up to 2022 (Figures 1–5). Whilst the data used in the SARIMA model to create forecasts used a time frame from quarter 1, 2017 to quarter 1, 2022.

The sample used comprises some of the biggest companies in the energy sector within Europe. The reason as to why large cap companies were chosen is because they are more willing to

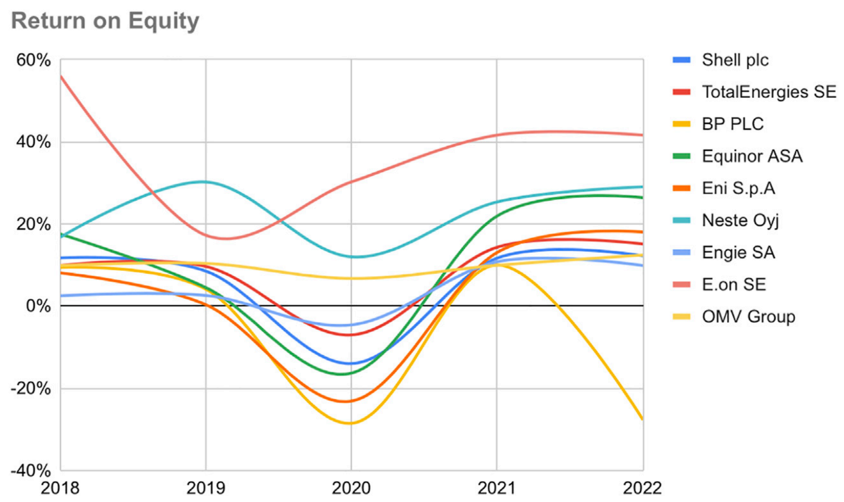

FIGURE 2
Line chart: Return on assets. Source: Own elaboration.

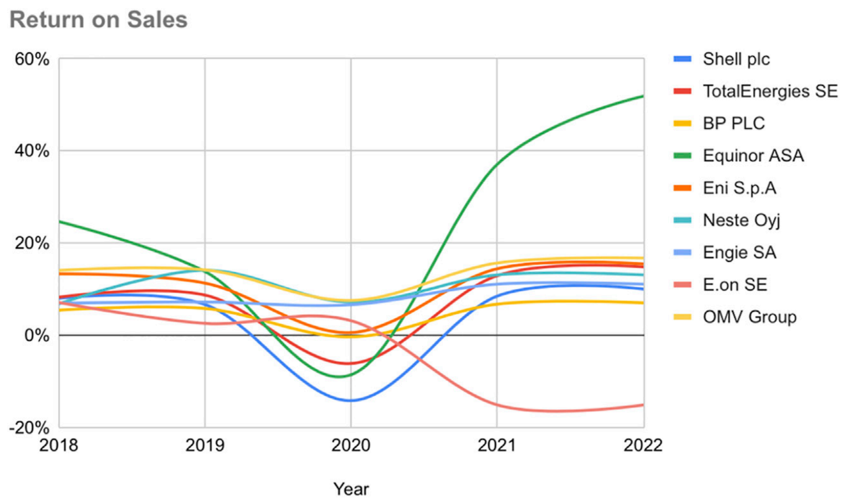

FIGURE 3
Line chart: Return on sales. Source: Own elaboration.

publish their ESG activities and the actions taken in order to implement them.

A potential proposal is that investor returns are higher when it takes into account environmental, social and governance factors. ESG may be positively linked to a firm's performance hence, increasing the return for investors. As the times are changing investors are more concerned about what firms are doing to be more environmentally friendly, their selling practices and product labelling as well as the governance factors such as board diversity and corruption free practices.

The slack resource theory posits that, rather than firms' ESG impacting CFP, improved CFP leads to enhanced ESG outcomes (Waddock and Graves, 1997). An improved financial position allows enterprises to invest greater monetary resources in activities that are more socially responsible and can include employee relations, the environment and society (Preston and O'Bannon, 1997).

An overview of the key variables used in this paper are presented in the table below (Table 1).

Most of the financial data was obtained from published financial statements by the companies as well as yahoo

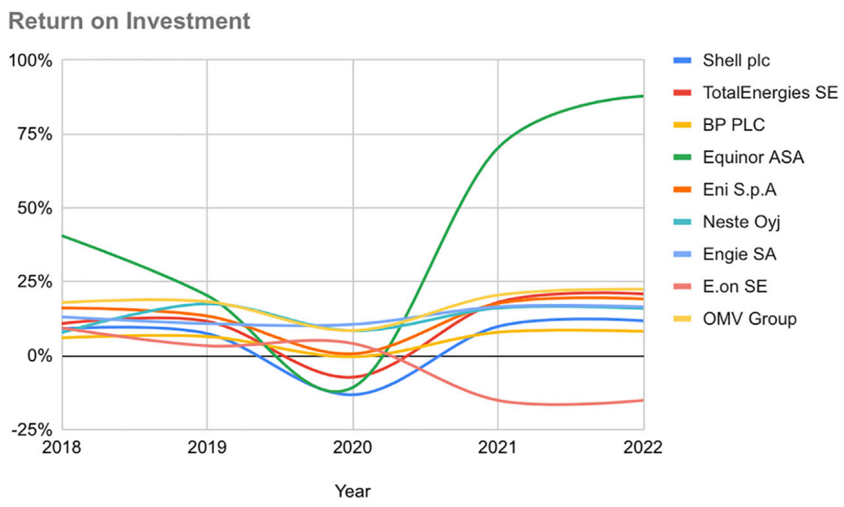

FIGURE 4
Line chart: Return on investment. Source: Own elaboration.

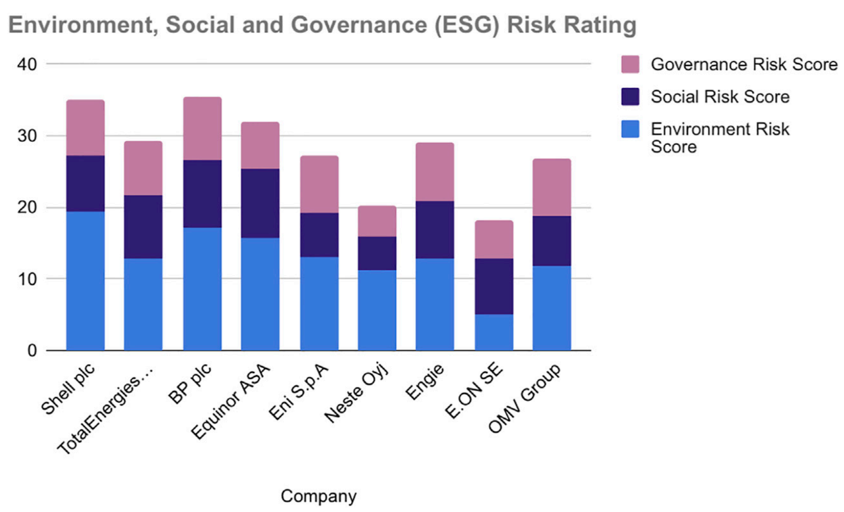

FIGURE 5
Stacked ESG column chart. Source: Sustainalytics, 2022.

finance which has compiled data of financial statements which were extremely helpful.

3.8 Findings

This section will focus on the results obtained from using financial models and different statistical calculations which have been revealed through analysing the data.

The table below is a summary of the sample used in this paper (Table 1). It consists of nine companies within the European Energy sector. In an attempt to diversify the sample, companies from 7 European countries were used. These companies are all considered large caps as they all have a market value of €10 billion and above.

In general, market capitalization correlates to a firm's level of development. Large-cap stock investments are usually considered more cautious than small-cap or midcap stock investments, perhaps providing lower risk in return for far less aggressive potential growth. Midcap equities, in contrast, fall on the risk and reward continuum between large and small companies. Market capitalization is derived by multiplying the number of shares

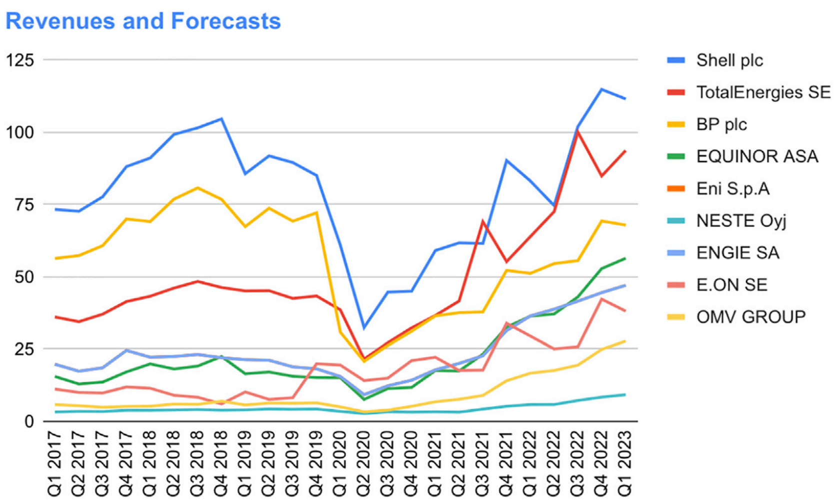

FIGURE 6
Line chart: forecasts and revenues. Source: Own elaboration.

TABLE 1 List of factors for energy sector to generate better ESG reports. Source: Own elaboration.

Environmental (E) index	Social (S) index	Governance (G) index
GHG Emissions	Labour management	Board diversity
Material sourcing	Health and Safety	Executive Pay
Toxicity and waste production	Customer privacy	Corruption free
Opportunities in renewable energy	Selling practices and product labelling	Tax transparency

TABLE 2 ESG risk rating scale. Source: Sustainalytics, 2019.

Negligible	Low	Medium	High	Severe
0–10	10–20	20–30	30–40	40+

outstanding by the last closing price (Bloomberg, 2020) The value is expressed in billions of euros. The market capitalization is the value of the company's outstanding shares minus treasury shares. If the corporation has numerous shares, the market capitalization of all common stocks at the conclusion of the time is representative. As a result, it becomes a type of risk gauge because it demonstrates the firm's financial capability (Corporate Finance Institute, 2020).

In the case of the ROE indicator it can be seen that E. on SE has quite a high ROE in 2018 of nearly 60% which can easily be attributed to the fact that they are able to use investment funds efficiently in order to generate earnings growth. In addition Neste Oyj, also is seen to have a high ROE which suggests that they have generated great profits with minimal equity capital. It also means that they have been able to obtain steady earnings growth whilst giving the majority of its profits back to its shareholders. Evidently there has been a great drop in ROE for the other companies included in the sample during the period of 2020 where most companies were greatly affected by the COVID-19 pandemic, however an improvement in ROE can be seen within the next few years. Lastly BP plc had a poor ROE from 2021 to 2022 this is due to an attempt to cut debt below €33 billion where the company decided to sell parts of its shares in the Oman gas field. It is also worth mentioning that during this time BP's renewables projects were resulting in losses.

Regarding the ROA indicator, the sample in this paper consists of companies within the same industry making it easier to analyse as they would have a similar asset base. The results from ROA as seen in the Figure 2, mimic similar results as the ones seen in the ROE graph. Neste Oyj can be seen to have a high ROA indicating that its operating cash is adequate enough to cover its debt. Similarly to ROE there was an occurrence of some negative readings especially around 2020 due to the pandemic. Furthermore, BP plc seems to also have a declining ROA from 2021 to 2022 as they are looking to sell most of their assets in order to reinvest the money into assets that are of renewable energy.

TABLE 3 Latent variables and observable variables: Source Own elaboration.

Latent variables		Observable variables
Financial Situation	ROE	Return on Equity
	ROA	Return on Assets
	ROS	Return on Sales
	ROI	Return on Investment
Social factors	ESG score	Environmental, Social and Governance index
Unobservable Factors	Region	Europe
	Time	Year Variable

TABLE 4 Summary of the most important figures regarding financial and social concerns. Source: Own elaboration.

	Mean	Median	Std.Dev	Max	Min
ROE	10.69	10.40	0.16695936	55.97	−7.88
ROA	3.2	3.9	5.163124993	18.6	−7.88
ROS	9.01	8.29	0.1148269251	51.90	−15.09
ROI	13.14	10.90	0.1793279666	87.82	−15.10
ESG SCORE	28	29	5.903812328	35	18

The ROS indicator shows that most of the companies have steady ROS despite a decline in the year 2020 due to the pandemic mentioned previously. However there is an unusual increase in ROS for Equinor ASA which was due to increased liquid and gas prices as well as powerful productions and an increase in gas production.

The graph in Figure 4 shows the ROI for the companies within the sample and shows a stable ROI until 2019 to 2020 where the pandemic really affected these businesses. Equinor ASA has an unusually high ROI which exemplifies its potential to outperform other companies within the same industry due to it accelerating growth. In addition, it can be seen that E. on SE has a declining ROI from the year 2020 onwards. This can be due to a great decrease in demand from industrial and commercial power usage.

Using the sample of companies in the energy industry a graph was developed to show each company's ESG risk rating and how each ESG factor contributes to the overall ESG risk (Table 2). As seen in Figure 5 the ESG risk ratings for the following companies fall within a total score of 35 and a minimum total score of 18. Shell plc and BP plc share a similar total score of 35 suggesting that they fall within the "high" category. This means that they have increased unmanaged risks. E. on SE can be seen to have a lower total score of 18 thus placed in the "low" category according to Sustainalytics ESG risk rating scale (Tables 3, 4 and 5). This means that it has reduced unmanaged risk.

In this paper, a (0,1,1), $(0,1,1)_4$ SARIMA model was applied in order to forecast revenues for the next 4 quarters using the nine companies previously mentioned. Data from quarter 1, 2017 to quarter 1, 2022 was used to test for seasonality while incorporating an autoregressive integrated moving average model. After calculations to find the constant, theta (θ) and

TABLE 5 Summary of the sample used in this research. Source: Bloomberg, 2022.

Company	Sub Industry	Country	Market cap (billion)
Shell plc	Oil and gas	United Kingdom	€206.43
TotalEnergies SE	Oil and gas	France	€141.25
BP plc	Oil and gas	United Kingdom	€99.85
Equinor ASA	Oil and gas, solar and wind energy	Norway	€112.99
Eni S.p.A	Oil and gas	Italy	€50.43
Neste Oyj	Oil refining and marketing	Finland	€32.79
Engie	Utilities (electricity, renewable energy and petroleum)	France	€30.84
E.ON SE	Utilities (electricity)	Germany	€25.78
OMV Group	Oil and gas and petrochemicals	Austria	€17.47

phi (φ) were completed, they were used to generate revenue forecasts for quarter 2, 2020 until quarter 1 2023.

Figure 6 shows the revenues for the chosen nine companies and their potential forecasts for the next four-quarters. As seen, some of the market leaders include Shell plc, BP plc and TotalEnergies with declines in revenues during Q1 2020 and Q2 2020 due to the pandemic and then a pattern in revenues begin to form in quarter 3, 2021 as the estimates obtained using the SARIMA model are plotted on the graph until quarter 1 2023. With these results it is possible for potential investors to analyse how a company's performance can impact their returns, whilst still focusing on ESG activities.

4 Discussion and conclusions

The aim of this paper is to investigate the correlation between investor returns and ESG activities within the energy industry. This section will present the key arguments and main takeaways, illustrate and critique them in relation to the research objectives. It will also highlight how it corresponds to earlier studies. This section will also include limitations of the energy sector in relation to ESG as well as limitations of the study and will conclude with recommendations.

4.1 Conclusion and managerial implications

Environmental, social, and governance (ESG) investing has sparked a widespread curiosity by many asset managers. The value of ESG-focused portfolios across major markets surpassed US$30 trillion in 2019. ESG investing is important to investors for a minimum of two reasons. For starters, by emphasising ESG investing, ethically responsible investment activities are strongly encouraged. Secondly, ESG investing is rapidly being thought of as a way to improve performance of a managed portfolio, thus improving returns while decreasing portfolio risk (Broadstock et al., 2021).

Investors are mostly drawn to organisations that have a high number of assets to invest in and it causes the stock market to rise in value. This idea is reinforced by Rahmandia (2013) and Zaki, et al. (2017), who claim that a company's scale has a favourable impact on stock prices.

Oil and gas corporations' social and governance activity is frequently disregarded in favour of environmental exhortations. However, In the past, the energy sector has been a pioneer in creating excellent health, safety, and governance rules. During the last two to three years, the emergence of ESG has resulted in significant adjustments toward focusing on "E" factor and "S" factor and organisational cultures are rapidly evolving to tackle these issues.

Following the Paris Climate Agreement (United Nations, 2015), ESG has advanced dramatically, and numerous worldwide efforts are working to advance ESG standards. Previously, environmental reviews were best suited, with little attention for emissions or impacts farther along the value chain. ESG has become its own entity, propelled by huge institutional investors and foreign financiers. Finance and investment must be the driving forces behind transformation. As a result, as a worldwide corporation, they will select financiers who prioritise ESG in their strategy, as it is what potential investors expect.

The energy sector must recognise the role that governments all over the globe have undertaken in conditioning the people to the usage of fossil fuels. Investors are aware of the shifting market trends and are monitoring the actions done in accordance. Technology applications in the decarbonization of the energy sector should be a primary priority for enterprises in the energy and gas industry in order to adapt to shifting market demands and restore investor confidence.

As most oil and gas firms will likely continue to invest in traditional production, industry leaders are prioritising sustainable energy projects as compared to other firms within the industry (Petroplan, 2021). The urge for resilient and secure practices is at the heart of the energy sector's change. A global appeal has been issued to investigate sustainable energy practices and to embrace safe processes.

Almost all energy companies considering investment and finance are building solid ESG frameworks with net-zero decarbonisation proposals. Investors are not exclusively focusing their financial choices upon how leaders incorporated ESG principles into their firms, but they are also advocating for quantitative and qualitative ESG criteria to thoroughly analyse whether firms can compete in the shift towards carbon-free energy.

As the energy industry is evolving it can be noted that there is a positive correlation between ESG activities within a company and investor returns considering that companies investing in ESG activities have higher or better financial performance. This in turn guarantees the chances of an investor receiving their returns. According to Cappucci (2017), full inclusion of ESG within the investment process is the ultimate ESG strategy. Therefore, allowing companies to attract financial capital by investing in ESG initiatives.

Furthermore, results from this research may have managerial implications. The thesis outcomes help Managers continue making strategic decisions relating to the ESG pillars that will keep investors satisfied and attract future investors willing to invest in future projects. Regarding the energy industry, some of the future projects may be linked towards renewable energy and low carbon energy. Managers may also have to understand investor behaviour and possibly find solutions to convince investors that they made the 'right' choice. This is because investor behaviour is solemnly based on cognitive, social and emotional factors that influence their decisions.

Lastly, it is crucial for managers to stay connected with market trends and this can apply to portfolio managers and business managers. For businesses it is key to know which areas may need improvement and which areas are performing well. This will allow for long term strategies to be created and thus being able to safe-proof investor funds. Eccles et al. (2017) suggested that incorporating ESG into an investment strategy can lead to higher risk-adjusted returns and long term value creation.

4.2 Limitations

ESG is a theoretical model for driving improved corporate operations and ensuring the survival of one's organisation from imminent environmental and social constraints. Reservations about the absence of standardisation and comparability of environmental disclosure, as well as modern viewpoints on ESG in the developing world, persist.

The documenting, consistency, and comparability of the ESG criteria remains the most significant impediment to pervasive transformation. As things currently stand, businesses can select the structure that best suits their needs and allows them to offer a flattering account of activities. Businesses are now disclosing ESG accomplishments, which helps finance and investment comprehend exposure of assets and select the best suited customers.

As Renneboog et al. (2008) stated, in a competitive market, a company reducing its profits in order to pursue social and environmental goals may not endure the competition and disciplining actions from the market for corporate control.

In addition, there seems to be a challenge to strike a balance given the need for cleaner fuels and the societal ramifications of limiting additional gas production on the continent. This leads back to the necessity for better disclosure of objectives and behaviours, as well as relevant perspectives. As seen in the findings mentioned earlier, BP pc has been shifting towards renewables and low carbon energy projects, however they have experienced low revenues on these projects as it currently seems to be less profitable than their previous projects. According to the OECD (2020), due to indirect pressure, firms are attempting to strengthen their sustainability efforts which can be costly whilst showing their financial resilience.

With regards to this paper some limitations include the sample as companies within this sample are only European, making it difficult to generalise the results to other continents. Furthermore, the sample only consists of companies within the energy industry with a similar asset base, therefore making it complicated to generalise to smaller companies within the same industry or even larger companies outside the energy sector. It also affects the validity of the results as only a small sample of nine companies were incorporated in this study. A larger sample would have yielded more accurate results making it easier to identify a significant relationship within the data.

4.3 Recommendations

With oil prices increasing and governments encouraging measures to solve the climate catastrophe, some experts and ESG investors predicted oil and gas corporations to reinvest their earnings in low-carbon technologies. With this being done successfully companies can fortify their businesses by repaying debts amassed during the Covid-19 pandemic, thus increasing its dividends and purchasing back their stock.

Companies within the energy industry especially within the oil and gas sector should begin their transformation to renewable energy as well as low carbon energy. They should opt to invest in projects that assist in energy transition and this could include hydrogen production, wind farms and electric charging networks considering the shift towards electric vehicles is currently taking place. Investing in energy transition now will make it easier for these firms to have a greater long term environmental impact, meet future demand and compete with other players within the industry as well as improve their access to financial services.

Firms within this industry should consider publishing full ESG reports that thoroughly expound on their ESG initiatives and how it will affect the company's future as well its performance overall. This would boost a firm's worth by demonstrating its social responsibility and might have an impact on good occurrences while eliminating unfavourable events.

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

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

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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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2022.1031827/full#supplementary-material

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Does digital financial inclusion matter for firms' ESG disclosure? Evidence from China

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Using a sample of Chinese listed firms during 2010–2018, this paper examines the relationship between digital financial inclusion and firms' ESG disclosure. The results show that 1) digital financial inclusion can significantly promote firms' ESG disclosure; 2) the promotion effect of digital financial inclusion on firms' ESG disclosure occurs mainly through channels including the coverage breadth and usage depth; and 3) for firms with higher financing constraints and state-owned enterprises, the promotion effect of digital financial inclusion on firms' ESG disclosure is more prominent. This paper provides relevant conclusions and insights for promoting firms' ESG information disclosure, integrating the digital economy, and encouraging innovation development.

KEYWORDS

digital financial inclusion, ESG disclosure, financing constraints, listed firms, China, ownership structure

1 Introduction

Environmental, social, and governance (ESG) has been gaining considerable importance in recent years, especially in developing sustainable strategies. With numerous financial, social, and environmental crises, investors' social awareness has increased significantly. At the G20 summits, China's "High Principles of Digital Financial Inclusion" have been considered one of the guiding documents for the international community in the field of digital financial inclusion. This shows the international community's recognition of China's achievements in the field of digital finance. Digital financial inclusion can promote economic inclusion and growth using current internet technology and through computer information processing, data integration, and other related technologies for long-term modern financial exclusion. Moreover, it is an excellent way to enjoy formal financial services and all forms of sustainable development governance and to achieve ESG performance growth.

The ESG disclosure of firms has been a worldwide concern (Minutolo et al., 2019; Huang et al., 2022), especially in developing countries like China (Broadstock et al., 2021; Zhang et al., 2022). Most studies have discussed firms' ESG disclosure from the perspectives of two main trends. On the one hand, the mainstream literature has relied on the economic consequences of firms' ESG disclosure, including market information asymmetry (Siew et al., 2016), firm value (Yu et al., 2018; Wong et al., 2021), equity market liquidity (Egginton & McBrayer, 2019), financial performance

(Minutolo et al., 2019), and earnings management practices (Kolsi et al., 2022). On the other hand, a growing strand of literature has started to take influence factors of firms' ESG disclosure into consideration, such as board gender (Manita et al., 2018), CEO tenure (McBrayer, 2018), CEO power (Velte, 2019), and board structure (Husted & de Sousa-Filho, 2019), which is beneficial to empowering firms' ESG disclosure and alleviating ESG information asymmetry of the capital market. The aforementioned trends mainly focus on the perspective of firms' characteristics. However, they ignore the potential effects of digital financial inclusion on firms' ESG disclosure. Therefore, the current paper aims to fill this gap by analyzing the relationship between digital financial inclusion and ESG disclosure of firms.

In China, firms' ESG disclosure has been vigorously promoted and developed. In 2018, the Asset Management Association of China issued "the Green Investment Guidelines (for trial implementation)," which proposed the ESG disclosure framework for listed firms and required listed firms to disclose ESG information. The ESG disclosure system has accelerated the green transformation and development speed of Chinese listed firms, improved the transparency of the capital market, and been conducive to reducing information asymmetry between firms and investors. Therefore, facilitating firms' ESG disclosure is conducive to stakeholders forming a better understanding of firms, reducing the uncertainty risk brought by information asymmetry, and improving the stability of the stock market. Therefore, we examine the relationship between digital financial inclusion and firms' ESG disclosure in the Chinese institution background. This will help clarify the driving force of firms' ESG disclosure. To some extent, the current paper not only has certain practical significance in China but also provides insights into the development of ESG disclosure in emerging market countries.

Additionally, a growing strand of literature has discussed how digital financial inclusion alleviates corporate financing constraints and information asymmetry, potentially affecting firms' ESG disclosure (Fuster et al., 2019; Murinde et al., 2022). Hence, with the boosting of digital financial inclusion, it is puzzling that few studies have focused on ESG disclosure consequences caused by digital financial inclusion at the firm level (Siew et al., 2016; Zhang et al., 2022). So far, there is no clear conclusion about the impact of digital financial inclusion on firms' ESG disclosure. The relationship between digital financial inclusion and firms' ESG disclosure as a critical aspect of strategic decision-making remains unexplored (Broadstock et al., 2021; Luo et al., 2022). It is necessary to further explore whether and how digital financial inclusion affects firms' ESG disclosure.

This paper explores the relationship between digital financial inclusion and firms' disclosure of ESG. First, the paper merges panel data of Chinese A-share nonfinancial listed firms, including disclosure of ESG collected from the Bloomberg database and the digital inclusive finance index of Chinese prefecture-level cities during 2011–2018. Then, the paper examines the effect of digital financial inclusion on firms' disclosure of ESG information based on the fixed-effect OLS model. The empirical results show that 1) digital financial inclusion can significantly promote firms' ESG information disclosure; 2) the promotion effect of digital financial inclusion on firms' ESG information disclosure occurs mainly through channels including the coverage breadth and usage depth; and 3) for firms with higher financing constraints and state-owned enterprises, the promotion effect of digital financial inclusion on firms' disclosure of ESG information is more prominent.

This study contributes to digital financial inclusion and firms' ESG disclosure literature in three ways. First, the study enriches the literature on the effect of digital financial inclusion on corporate strategic decision-making from the perspective of firms' ESG disclosure. It can help us achieve a deeper understanding of how digital financial inclusion can influence corporate ESG behavior and information disclosure outcomes (Sedunov, 2017; Fuster et al., 2019; Goldstein et al., 2019; Thakor, 2020). Second, this study advances the investigation of the influence factors of firms' ESG disclosure from the external financial environment perspective (i.e., digital financial inclusion). The study expands the understanding of the factors affecting firms' ESG disclosure and goes beyond previous studies based on the single perspective of corporate characteristics (Manita et al., 2018; McBrayer, 2018; Husted & de Sousa-Filho, 2019; Velte, 2019). Third, the paper extends the understanding of the consequences of digital financial inclusion at the firm level and provides insights into the financial-development-driven force of firms' ESG disclosure in emerging market countries (Husted & de Sousa-Filho, 2019; Jia & Lin, 2020; Li et al., 2021; Zhang et al., 2022).

The remainder of this paper is structured as follows: Section 2 consists of the literature review and hypothesis development. Section 3 describes the empirical strategy, including the empirical models, sample selection, and variables. Section 4 consists of the benchmark results, heterogeneous analysis, and robustness check. Section 5 provides the conclusions and insights.

2 Theoretical analysis and hypothesis development

The development of digital financial inclusion has improved the information environment of companies and thus facilitated their ESG disclosure behavior. On the one hand, it has helped reduce information asymmetry between investors and firms (Goldstein et al., 2019). According to the signaling theory (Arvidsson & Dumay, 2022), the development of digital financial inclusion reduces information asymmetry between firms and external investors (Lv & Xiong, 2022), allowing firms to release positive signals to external investors. This in turn reduces the stock market uncertainty risk and attracts more

TABLE 1 Variable definitions.

Variable	Definition
Dependent variable	
ESG	Bloomberg rating is based on the environmental, social, and governance CSR disclosure index, ranging from 0 to 100
Explanatory variable	
DFI	The general index of financial inclusion indicates the development status of digital inclusive finance in China. The three second-level indicators, respectively, represent the breadth of coverage, usage depth, and digitalization degree of digital financial inclusion
Control variable	
STATE	A dummy variable that equals 1 if the firm pertains to the private sector and 0 otherwise
SIZE	Natural logarithm of total assets
LEV	Ratio of total liabilities divided by total assets
ROA	Ratio of net profits relative to total assets
BOARD	Natural logarithm of the number of board members
BOTH	A dummy variable equal to 1 if the CEO is also the chairman of the board and 0 otherwise
SR	The proportion of shares held by the top management team to the total share capital

investment. Firms' ESG disclosure releases signals to stakeholders that the firm is not entirely profit-seeking and selfish (Bhandari et al., 2022), which builds a good image of the firm. The firm continuously accumulates and forms reputational capital, actively engages in ESG activities, and releases positive ESG signals, which aids the firm's disclosure of more ESG information. On the other hand, the development of digital financial inclusion helps alleviate information asymmetry between firms and financial institutions (Sedunov, 2017), and external financial institutions can assess the financial status and risk level of firms with diversified digital means (Gomber et al., 2017). To increase financial institutions' willingness and enhance firms' credit financing ability, firms will engage in and disclose more information related to ESG, aiming to send a signal to the market that the firms are practicing the concept of sustainable development. Firms desire to obtain a positive response from relevant investors by showing ESG green advantages. Therefore, with the development of digital financial inclusion, firms will engage in more ESG activities and carry out more ESG information disclosure.

The development of digital financial inclusion helps managers implement the concept of sustainable development, avoid short-sightedness, and enhance the ability of enterprises to cope with risks (Fuster et al., 2019; Yin et al., 2019). According to the upper echelon theory (Hambrick & Mason, 1984), with the development of digital financial inclusion, managers can identify and approve of the ESG concept (Yonker, 2017). The fulfillment of firms' ESG social responsibility also lies in meeting the demands of stakeholders, creating a good external environment for corporate development, reducing potential risks of firms (Esposito De Falco et al., 2021), and thus promoting corporate ESG to engage in information disclosure. Furthermore, the development of digital inclusive finance has improved the corporate financing environment (Sedunov, 2017), reduced the cost of external financing, facilitated access to external financing (Fuster et al., 2019), helped enhance the market competitiveness of enterprises, and increased corporate value (Murinde et al., 2022). Thus, it has allowed firms to have more liquidity and cash flow and increased the level of shareholder wealth (Thakor, 2020), providing more support for enterprises to engage in ESG activities and promoting firms to engage in more ESG behaviors, including ESG information disclosure.

Hypothesis. Digital financial inclusion is positively associated with firms' disclosure of ESG.

3 Empirical models, sample selection, and variables

3.1 Empirical models

To estimate the effects of digital financial inclusion on firms' disclosure of ESG, we used a regression model. We defined the model as follows:

$$ESG_{i,t} = c + \beta_1 DFI_{i,t} + \gamma.CVs_{i,t} + \mu_i + \theta_t + e_{i,t} \tag{1}$$

where i and t indicate the firm and year, respectively; the dependent variable *ESG* represents a firm's disclosure of ESG; *DFI* refers to the digital financial inclusion index of the firm's registered address; and *CVs* refer to control variables, which aim to control other heterogeneous characteristics at the firm level. This study controlled for state-owned enterprise (*SOE*), firm size (*SIZE*), leverage (*LEV*), return on asset (*ROA*), board size (*BOARD*), power concentration (*BOTH*), and shareholder ratio of the top management team (*SR*). Furthermore, industry-specific fixed effects μ_i were added to the regression to account for industry-specific characteristics. In contrast, time-specific fixed effects θ_t were used to capture all time-variant macro-level factors common to firms. *c* refers to the constant term. To account for potential serial correlation and heteroskedasticity, we clustered standard errors at the industry level.

In Model (1), the coefficient of interest is β_1, which indicates the effect of digital financial inclusion on firms' disclosure of ESG. β_1 should be significantly positive because digital financial inclusion can promote firms' disclosure of ESG.

3.2 Sample coverage and data sources

We combined three data sources to examine the effect of digital financial inclusion on firms' disclosure of ESG. The first data source was the China Stock Market & Accounting Research database, which contains detailed information about all Chinese listed firms' annual reports and firms' financial information. The second data source was the digital financial inclusion index database, named "The Peking University Digital Financial Inclusion Index of China." It is the most comprehensive online digital financial inclusion database and provides detailed Chinese prefecture-level data on the digital financial inclusion index, which comprises the digital financial inclusion index and other essential dimensions (such as coverage breadth, digitization level, and usage depth). The third database was the Bloomberg ESG disclosure score. Bloomberg provides ESG data to more than 9,000 companies in more than 83 countries from public documents, such as social corporate responsibility reports, corporate annual reports, and corporate websites.

We chose all Chinese nonfinancial listed companies (excluding enterprises in the financial and real estate industries) listed on the Shanghai and Shenzhen exchanges from 2011 to 2018. We obtained our regression sample for the empirical analysis by merging the aforementioned three databases through manual matching of firms' registered addresses and names by year.

TABLE 2 Summary statistic.

Variable	N	Mean	SD	Min	Max
ESG	7262	20.049	6.447	1.24	61.722
DFI	7262	189.264	63.753	21.26	302.98
SIZE	7262	22.926	1.315	19.198	28.509
LEV	7262	0.468	0.235	0.008	8.009
ROA	7262	0.045	0.126	−3.911	7.445
BOARD	7262	2.185	0.206	1.099	2.89
BOTH	7262	0.2	0.4	0	1
SR	7262	0.082	0.182	0	5.91
STATE	7262	0.527	0.499	0	1

We obtained our regression sample for the analysis by manually matching the firms' registered addresses through a merger of the two databases. Following the previous research (Ding et al., 2018), we imposed the following restrictions: 1) we deleted firms from the financial industry and 2) we deleted firms that were specially treated. We winsorized the continuous variables at the 1% and 99% levels to minimize outlier effects. Table 1 lists the definitions of all the variables, while Table 2 reports the summary of statistics.

3.3 Disclosure of environmental, social, and governance

ESG scores comprised three fundamental dimensions: environmental, social, and governance. Within all dimensions, the scores range from 0 to 100, and the maximum value represents the enterprise's highest level of sustainable activity. ESG evaluates enterprises based on industry attributes, which is a relative value. We defined each company's ESG score by the Bloomberg ESG disclosure score. Bloomberg provides ESG data to more than 9,000 companies in more than 83 countries from public documents, such as social corporate responsibility reports, corporate annual reports, and corporate websites. Bloomberg established the ESG database in early 2008. The ESG Yuan Shu score algorithm is based on the global reporting initiative for enterprise sustainable development report standards. These data points are mainly disclosed related to social environment corporate social responsibility performance. In 2010, the ESG team increased the data points to 101 points through additional "Bloomberg indicators." These additional indicators mainly disclosed the activities of relevant companies in communication, learning, and strengthening awareness of corporate responsibility, including governance related to the social environment. The Bloomberg's ESG database provides enough information to disclose CSR activities and explore the relationship between digital financial inclusion and CSR activities.

3.4 The digital financial inclusion index

Thanks to the efforts of the Chinese central and local governments and the Peking University Digital Financial Research Center, "The Peking University Digital Financial Inclusion Index of China" has adopted the aforementioned database to measure digital financial inclusion (Bollaert et al., 2021; Lv & Xiong, 2022).

The general index of financial inclusion indicates the development status of digital inclusive finance in China. The three second-level indicators, respectively, represent the breadth of coverage, usage depth, and digitalization degree of digital inclusive finance. The main data source was the Alipay ecosystem, which

TABLE 3 Baseline regression results.

Dep. = ESG	Benchmark model		Alternative DFI index		
variable	Index aggregate		Coverage breadth	Usage depth	Digitization level
	(1)	(2)	(3)	(4)	(5)
DFI	0.037***	0.033***	0.020***	0.031***	0.002
	(0.009)	(0.005)	(0.003)	(0.006)	(0.001)
SIZE		1.930***	1.940***	1.937***	1.994***
		(0.213)	(0.217)	(0.211)	(0.231)
LEV		−1.481**	−1.538**	−1.410**	−1.714**
		(0.665)	(0.674)	(0.643)	(0.688)
ROA		0.077	0.058	0.044	−0.042
		(0.626)	(0.637)	(0.644)	(0.651)
BOARD		0.132	0.103	0.130	−0.050
		(0.654)	(0.668)	(0.651)	(0.696)
BOTH		−0.457*	−0.450*	−0.464*	−0.436
		(0.250)	(0.252)	(0.249)	(0.258)
SR		−0.539	−0.534	−0.441	−0.323
		(0.582)	(0.579)	(0.527)	(0.485)
STATE		1.334***	1.308***	1.393***	1.280***
		(0.327)	(0.323)	(0.311)	(0.284)
Constant	12.966***	−30.520***	−28.265***	−30.429***	−25.012***
	(1.768)	(4.601)	(4.398)	(4.632)	(4.370)
N	7,262	7,262	7,262	7,262	7,262
R^2	0.111	0.263	0.260	0.266	0.253
Controls	No	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
F	16.05	88.54	92.70	94.87	129.4

Note: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. Values in parentheses are clustering standard errors at the firm level. Regressions have constant terms but are not shown.

mainly describes the development level of digital inclusive finance in different regions. It covers 31 mainland provinces, 377 cities above the prefecture level, and nearly 2,800 counties. The explanatory variable data selected in this paper were from "The Peking University Digital Financial Inclusion Index of China (2011–2020)," released by Peking University.

3.5 Other variables

Following the previous literature (Gulen & Ion, 2016; Ding et al., 2018), we defined the measurement of the other variables as follows: state-owned enterprise (*SOE*), measured by a dummy variable equal to 1 if the firm's ownership is state owned and 0 otherwise; firm size (*SIZE*), measured by the natural logarithm of total assets; leverage (*LEV*), the ratio of total liabilities divided by total assets; return on asset (*ROA*), measured by the ratio of net profits relative to total assets; board size (*BOARD*), measured by the natural logarithm of the number of board members; and power concentration (*BOTH*), measured by a dummy variable equal to 1 if the CEO is also the chairman of the board and 0 otherwise. The shareholder ratio of the top management team (*SR*) is measured by the proportion of shares held by the top management team to the total share capital.

4 Results and discussion

4.1 Baseline regression

Table 3 shows the estimated results of the benchmark regression model. Three alternative indexes of digital financial

TABLE 4 Test of the effect of financial constraint.

Dep. = ESG	**Benchmark model**			
variable	**FC_high**	**FC_low**	**FC_high**	**FC_low**
	(1)	**(2)**	**(3)**	**(4)**
DFI	0.060***	0.014***	0.044***	0.019***
	(0.006)	(0.004)	(0.005)	(0.004)
SIZE			3.156***	0.576***
			(0.119)	(0.131)
LEV			−1.055	−0.787**
			(0.808)	(0.343)
ROA			4.919**	0.089
			(2.303)	(0.501)
BOARD			0.258	0.452
			(0.487)	(0.457)
BOTH			−0.642**	−0.467**
			(0.297)	(0.192)
SR			−2.337**	−0.801**
			(1.081)	(0.395)
STATE			0.537**	1.627***
			(0.266)	(0.191)
Constant	10.070***	15.656***	−62.569***	1.071
	(1.158)	(0.764)	(2.924)	(2.965)
N	3,631	3,631	3,631	3,631
R^2	0.118	0.076	0.296	0.120
Controls	No	No	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
F	105.1	11.29	129.8	24.00

Note: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. Values in parentheses are clustering standard errors at the firm level. Regressions have constant terms but are not shown.

TABLE 5 Test of the impact of SOE.

Dep. = ESG	**(1)**	**(2)**	**(3)**	**(4)**
variable	**SOE**	**Non-SOE**	**SOE**	**Non-SOE**
	ESG	**ESG**	**ESG**	**ESG**
DFI	0.063***	0.011**	0.042***	0.021***
	(0.005)	(0.005)	(0.005)	(0.005)
SIZE			2.111***	1.547***
			(0.079)	(0.107)
LEV			−2.115***	−0.985**
			(0.565)	(0.500)
ROA			0.413	0.002
			(0.701)	(1.036)
BOARD			−0.470	1.195**
			(0.464)	(0.511)
BOTH			−0.823**	−0.390*
			(0.334)	(0.202)
SR			−17.454***	−0.502
			(4.530)	(0.417)
Constant	9.781***	16.416***	−33.321***	−22.218***
	(0.956)	(0.999)	(1.981)	(2.637)
N	3,899	3,597	3,829	3,433
R^2	0.150	0.085	0.296	0.158
Controls	No	No	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
F	149.7	4.970	141.0	42.94

Note: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. Values in parentheses are clustering standard errors at the firm level. Regressions have constant terms but are not shown.

inclusion (*DFI*), namely, breadth (coverage breadth), depth (usage depth), and digital level (digitization level), were employed to further test the effect of digital financial inclusion.

The regression results are as follows: under the benchmark regression, column 2) of Table 3 shows that the estimated coefficient of *DFI* is 0.033, which is significantly positive at 1%, thus indicating that the development of digital financial inclusion is significantly positively associated with firms' ESG disclosure. This paper also employed three alternative indexes of digital financial inclusion, namely, breadth (coverage breadth), depth (usage depth), and digital level (digitization level) results, as columns (3), (4), and (5) show. The estimated coefficient of coverage breadth is 0.02 at the 1% significance level. The estimated coefficient of usage depth is 0.031 at the 1% significance level. The aforementioned results support our hypothesis that digital financial inclusion can effectively promote firms' ESG disclosure.

Based on the estimation results in column 2) of Table 3, we find that a one-standard-deviation increase in digital financial inclusion raises a firm's ESG disclosure score by 6.27 points, obtained by multiplying the standard deviation of the digital financial inclusion measure by the estimated coefficient. Considering that the mean of ESG disclosure is 20.049, this effect is also economically significant.

4.2 Additional analyses

4.2.1 Impact of financial constraints

Following the literature (Hadlock & Pierce, 2010), we calculated the absolute value of the SA index to measure firms' financing constraints. The greater the absolute value of the SA index, the greater the corresponding financing constraint would be. We then adopted the sorting method to classify all

TABLE 6 Robustness check.

Dep. = ESG	Benchmark model		Alternative DFI index		
variable	Index aggregate1		Coverage breadth1	Usage depth1	Digitization level1
	(1)	(2)	(3)	(4)	(5)
DFI1	0.042***	0.036***	0.022***	0.034***	0.015***
	(0.011)	(0.006)	(0.004)	(0.007)	(0.004)
SIZE1		2.027***	2.037***	2.034***	2.100***
		(0.218)	(0.220)	(0.216)	(0.232)
LEV1		−1.856**	−1.954**	−1.745**	−2.226**
		(0.830)	(0.832)	(0.795)	(0.800)
ROA1		0.412	0.411	0.360	0.325
		(0.423)	(0.427)	(0.448)	(0.448)
BOARD1		0.289	0.279	0.270	0.160
		(0.717)	(0.730)	(0.714)	(0.763)
BOTH1		−0.518**	−0.517**	−0.523**	−0.512*
		(0.239)	(0.241)	(0.236)	(0.245)
SR1		−0.377	−0.385	−0.270	−0.208
		(0.557)	(0.558)	(0.504)	(0.482)
STATE1		1.228***	1.201***	1.297***	1.189***
		(0.381)	(0.379)	(0.360)	(0.333)
Constant	13.143***	−32.432***	−30.223***	−32.285***	−24.568***
	(1.866)	(4.693)	(4.490)	(4.708)	(4.086)
N	6,146	6,146	6,146	6,146	6,146
R^2	0.102	0.264	0.261	0.267	0.255
Controls	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
F	15.69	77.80	74.50	96.36	113.8

Note: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. Values in parentheses are clustering standard errors at the firm level. Regressions have constant terms but are not shown.

firms into two groups using the median value of the absolute value of the SA index. Firms whose SA was above the median were defined to exhibit higher financing constraints, named FC_high. Firms whose SA was lower than the median were defined to exhibit lower financing constraints, named FC_low. We estimated our benchmark model on the subsample of firms with higher financing constraints and lower financing constraints. The results are shown in Table 4.

As shown in Table 4, compared with columns 3) and 4), the estimated coefficient of DFI in column 3) is 0.044 at the 1% significance level, which is larger than the estimated coefficient of DFI in column 4). Therefore, we conclude that for firms with higher financing constraints, the promotion effect of digital financial inclusion on firms' disclosure of ESG is more prominent.

4.2.2 Impact of state-owned enterprise

Compared to non-state-owned enterprises, state-owned enterprises will have more noneconomic goals in China (Ding et al., 2018). Therefore, the effect of digital financial inclusion on firms' ESG disclosure potential will vary across ownership. We estimate our benchmark model on the subsample of state-owned enterprises (SOEs) and non-state-owned enterprises (non-SOEs). The related results are shown in Table 5.

Based on the results in Table 5, according to the comparison of columns 3) and 4), the estimated coefficient of DFI in SOEs is 0.042 at the 1% significance level, which is larger than the estimated coefficient of DFI in non-SOEs. This shows that digital financial inclusion exerts a more prominent effect on firms' ESG disclosure in SOEs.

4.3 Robustness check

To mitigate the potential endogenous problems, we lagged the development level of regional digital financial inclusion with the control variables and conducted a regression analysis. The results are shown in Table 6.

According to Table 6, the estimated coefficient of DFI is still significantly positive at the 1% level. The lag breadth (coverage breadth 1), the lag depth (usage depth 1), and the lag digitization (digitization level 1) are all positively significant at the 1% level. Therefore, the results are still stable after considering the endogeneity problem.

5 Conclusion and discussion

Firms' disclosure of ESG is important for their strategic decision-making. However, the topic of whether digital financial inclusion can promote firms' disclosure of ESG needs to be further explored. We used the panel data for China's nonfinancial listed firms from 2011 to 2018 to estimate the effects of digital financial inclusion on firms' disclosure of ESG. The estimation results indicated that digital financial inclusion positively promotes firms' disclosure of ESG. The positive effect was evident in SOEs. We also paid close attention to the role of the information environment and financial constraints. The positive effect was favorable in firms with a better information environment and high financial constraints. Additionally, we determined that the positive effect was robust after the lag difference.

From the perspective of corporate ESG disclosure behaviors, this paper first provides micro-empirical evidence for evaluating the effects of digital financial inclusion. The study argues that digital financial inclusion is an essential factor that promotes firms' disclosure of ESG. Thus, on the one hand, a central government needs to develop digital financial inclusion and foster firms' ESG disclosure positively. The government's support for the development of digital financial inclusion can help firms engage in ESG and disclose it more actively, helping to achieve the goal of reducing peak carbon dioxide emissions and achieving carbon neutrality. Therefore, the government can advocate the development of digital financial inclusion and set multiple goals, including boosting digital financial inclusion and fostering firms' ability to engage in ESG activities. On the other hand, firms are induced to disclose high-quality ESG information and then make full use of the benefits of the growth of digital financial inclusion to improve their competitiveness and attract more investor attention and investment.

Finally, this paper did not assess the impact of digital financial inclusion on firms' ESG disclosure in different regions. Future studies can take various regional heterogeneities into consideration and re-examine the influence of digital financial inclusion on firms' ESG disclosure.

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 authors.

Author contributions

All authors contributed to the conception and design of study. Data collection and empirical study were conducted by YL. Supervision and writing of the first draft were performed by LW. YZ contributed to the critical revision of the manuscript and final approval of the version to be published. 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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Grandfathering or benchmarking: Which is more viable for the manufacturer's low-carbon activities?

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Under the emissions trading policy, two typical carbon allowance allocation rules of grandfathering and benchmarking are widely adopted in the present carbon markets. Based on the mathematical modeling method, this paper explores which allocation rule is more viable for manufacturers' low-carbon activities including abatement investment and remanufacturing activities. Meanwhile, the effects on total profit, total carbon emissions, consumer surplus, and social welfare are discussed through numerical analysis. The results show that benchmarking is more viable for abatement investment activities of manufacturers than grandfathering. Additionally, benchmarking is always more viable for remanufacturing activities of manufacturers only in a situation with a higher consumer low-carbon preference. Otherwise, which allocation rule is more beneficial for remanufacturing activities mainly depends on the abatement cost coefficient. Correspondingly, the higher the consumer low-carbon preference or the lower the abatement cost, the more viable the benchmarking is to achieve each performance target (e.g., total profit, emissions control, consumer surplus, and social welfare). Based on these findings, this paper also recommends managerial insights for manufacturers and policy implications for policy-makers.

KEYWORDS

grandfathering, benchmarking, emissions trading policy, abatement investment decision, manufacturing/remanufacturing decisions

1 Introduction

The outbreak of coronavirus disease 2019 (COVID-19) has induced a certain effect on the environment. Climate warming will be an even more rigorous issue and also widely concerning since the total greenhouse gas emissions (especially carbon dioxide) may exceed the level before the event considering the resumption of large-scale industrial production (Wang and Su, 2020). This calls for a cautious and opportune response from the global community to improve this situation (Li et al., 2022). Consequently, many countries have promulgated several carbon emission policies, such as mandatory carbon emission capacity, emission trading, carbon tax, and low-carbon offset (Song and Leng, 2012; Zhang et al., 2021). Among them, the emissions trading policy is more efficient in emission control and is widely adopted and implemented (Luo et al., 2016; Qiu et al., 2017; Huang et al., 2022). Under the emissions trading policy, enterprises could obtain initial carbon allowances from the government with or without payment and purchase or sell carbon credits in the carbon markets if necessary (Toptal et al., 2014; Xu et al., 2017).

As a vital foundation for designing the emissions trading policy, carbon allowances are mainly allocated free of charge to reduce resistance of enterprises and ensure easy implementation at the initial stage (Liao et al., 2015; Chang et al., 2017). For instance, at least 90% of carbon allowances are allocated free of charge in Shenzhen's emissions trading system (Yang W.et al., 2020). So far, there are two typical free allocation rules of grandfathering and benchmarking in the present carbon markets. Under grandfathering, the amount of free carbon allowances is fixed and determined by the historical carbon emissions of enterprises in the base year. Under benchmarking, the free allocated carbon allowances are associated with the industry benchmark emission intensity and total output (Neuhoff et al., 2006; Zetterberg, 2014; Ji et al., 2017). Concretely, the industry benchmark emission intensity is determined by the government at the beginning of the compliance period, and total carbon allowances are equal to the benchmark emission intensity times the enterprise's total output by the end of the current period (Yang W.et al., 2020). As we all know, the largest carbon market in the world—EU Emissions Trading System (EU-ETS)—and China's pilot carbon markets mainly adopt grandfathering and benchmarking. It is also one of the main motivations to carry out research focusing on these two allocation rules in this paper.

The manufacturing industry, as an essential part of society, is the main emitter of carbon dioxide. Rapid growth in manufacturing has drawn more attention to improving environmental quality (Farouq et al., 2021). Thus, in response to the emissions trading policy, low-carbon technology investments have been incorporated into operational planning by manufacturers (Yang W.et al., 2020). Some studies have shown that environmental quality can be effectively improved through technological changes (Huang et al., 2019; Yang L.et al., 2021). In practice, some manufacturers (e.g., Gree and Haier) have continuously developed and introduced abatement technologies, which undoubtedly makes significant contributions to the low-carbon upgrade of the industry and society (Meng et al., 2021). In 2021, Gree officially launched the photovoltaic (storage) direct-current air conditioning system, and it is estimated that this technology can reduce the carbon emissions of air conditioners by 85.7%. Moreover, as one of the effective ways to restore the value of waste products, remanufacturing is regarded as an essential means to achieve energy saving and carbon abatement. Large global manufacturers such as BMW, IBM, and Kodak are involved in remanufacturing activities and obtain considerable economic and environmental benefits (Ilgin and Gupta, 2011; Li et al., 2013). The emissions trading policy is believed to benefit low-carbon activities of manufacturers (Wang et al., 2017; Yang et al., 2018), but the performance of the different allocation rules is still unclear.

Previous studies on carbon allowance allocation rules mainly concentrated on the macro-level and single low-carbon activity. However, in reality, the macro-emission target must eventually be decomposed to the manufacturer's micro-operation level. For instance, in 2019, the "Regulation (EU) 2019/631 of the European Parliament and of the Council" issued by the European Union set CO_2 emission performance standards for new passenger cars and new light commercial vehicles, which indicates that automakers are given clear abatement targets. Moreover, manufacturers may simultaneously carry out several low-carbon operation activities to better achieve specific emission reduction targets. Taking Gree as an example, in addition to technological investments, it has also built some green recycling and remanufacturing bases and is committed to transforming production modes. Furthermore, manufacturers are more active in fulfilling social responsibilities, rather than focusing only on their own interests. The "2019 China Corporate Social Responsibility 500 Excellent Evaluation Report" shows that the manufacturing industry accounts for 41.25% of the shortlisted enterprises. Therefore, this paper considers a monopolistic manufacturer whose low-carbon activities include abatement investments and remanufacturing. Based on the emissions trading policy with two different carbon allowance allocation rules, some research questions will be answered in this paper: 1) how does the emissions trading policy affect manufacturers' abatement investments and remanufacturing integration decisions? 2) Which allocation rule (e.g., grandfathering and benchmarking) will better induce low-carbon activities (e.g., abatement investment and/or remanufacturing decisions) and achieve specific performance targets (e.g. total profit, total carbon emissions, consumer surplus, and social welfare)? 3) How do different situations (e.g., a higher/lower abatement cost and consumer low-carbon preference) affect the performance of each allocation rule?

To address these issues, this paper develops two nonlinear mathematical models under the emissions trading policy and explores the effects of two typical free allocation rules of grandfathering and benchmarking on abatement investment and manufacturing/remanufacturing decisions. Through theoretical analysis, which allocation rule is more viable for the manufacturer's low-carbon activities is mainly discussed. Meanwhile, based on multiple performance targets (e.g., total profit, total carbon emissions, consumer surplus, and social welfare), this paper explores the policy-maker's selection strategy of allocation rules and the effects of some crucial parameters (e.g., consumer sensitivity coefficient and abatement cost coefficient) on the results. Some managerial insights and policy implications are expected to be provided for low-carbon activities of manufacturers and policy design of policy-makers, respectively.

The remainder of this paper is organized as follows. Section 2reviews some relevant literature. Section 3 presents materials and research methods, including problem description and assumption statement, and mathematical model construction and analysis. Section 4 elaborates the comparative analysis of several performance targets under different allocation rules through numerical analysis. Finally, Section 5provides conclusions and future research.

2 Literature review

The relevant literature can be divided into the following two main streams: 1) the literature exploring the effect of carbon emission policies on production decisions with remanufacturing and/or abatement investment decisions and 2) the literature on different free carbon allowance allocation rules under the emissions trading policy.

In the first stream of the literature, several carbon emission policies are involved, such as mandatory carbon emission capacity and carbon tax (Liu et al., 2015; Dou et al., 2019; Shuang et al., 2019; Hu et al., 2020). Moreover, a large part of the literature is devoted to studying the effect of the emissions trading policy on remanufacturing decisions. For instance, Chai et al. (2018) identified several conditions that would benefit manufacturers with remanufacturing activities under the emissions trading policy. Yang L. et al. (2020) explored the impact of the emissions trading policy on the remanufacturing decision, total profit, and total carbon emissions under different recycling channels. Paying attention to the effect on recycling modes, Yang C. et al. (2021) found that the emissions trading policy can always reduce carbon emissions. Considering the uncertainty of the quality of recycled products, Zhao et al. (2021) studied the remanufacturing decision under the emissions trading policy and stated that manufacturers with dynamic carbon emissions have higher profits and fewer carbon emissions than those with fixed carbon emissions. Bai et al. (2022) further explored the effect of the emissions trading policy on remanufacturing activities and total carbon emissions with limited demand distribution information.

A few scholars recently studied the comprehensive issue of remanufacturing and abatement investment decisions under different carbon emission policies. Among them, substantial literature focuses on the impact of the carbon tax policy. For instance, considering monopolistic and competitive scenarios, Ding et al. (2020) investigated remanufacturing and emission reduction decisions under the carbon tax and take-back legislation. Alegoz et al. (2021) concentrated on pure and hybrid manufacturing/remanufacturing systems and carried out a comparative analysis of production and abatement decisions under a carbon tax policy. Wang and Wang (2021) proposed a differentiated carbon tax regulation across new and remanufactured products and explored the effect on manufacturing/remanufacturing and emission reduction decisions. However, the existing relevant literature is rarely involved in the emissions trading policy. Yuan et al. (2020) studied the pricing and emission reduction decisions of a remanufacturing supply chain system with dual-sale channels under the emissions trading policy.

It can be found that the aforementioned papers involving the emissions trading policy neglect alternative carbon allowance allocation rules. So far, most existing studies analyze the effect or performance of different carbon allowance allocation rules from a macro-perspective, such as Wu and Li (2020), Peng et al. (2021), and Tian et al. (2022), but few papers focus on relevant issues from a micro-perspective. Zhang et al. (2015) carried out a comparative analysis of pricing and emission reduction strategies under different allocation rules of grandfathering, benchmarking, and auction. Chang et al. (2017) mainly studied a two-stage manufacturing/remanufacturing decision issue considering grandfathering and benchmarking. Ji et al. (2017) investigated the effect of different allocation rules on retail and emission reduction decisions, total revenue, and social welfare. Yang L.et al. (2020) constructed a mathematical model to make optimal green technology investment and pricing decisions and analyzed the effect of grandfathering and benchmarking on operational decisions and total carbon emissions. Although the aforementioned papers regarding grandfathering and benchmarking are relevant to our study, very few literature studies addresses remanufacturing activity, and none of them considers the integrated issue of remanufacturing and abatement investment.

To sum up, our main contributions lie in the following three aspects: first, this paper contributes to the abatement investment and remanufacturing integration decisions under the emissions trading policy. Second, from the perspective of enterprise micro-operation, we explore the different effects of grandfathering and benchmarking on the aforementioned integrated emission control decisions, which is to verify which allocation rule is more viable for the manufacturer's abatement investment and/or remanufacturing decisions. The third contribution is in addressing the policy-maker's selection strategy of allocation rules based on multiple performance targets (e.g., total profit, total carbon emissions, consumer surplus, and social welfare) and exploring the effect of some crucial parameters (e.g., consumer sensitivity coefficient and abatement cost coefficient) on the results.

3 Materials and research methods

3.1 Problem description and symbol instruction

This study considers a monopolistic manufacturer engaged in the production and sales of both new and remanufactured

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TABLE 1 Decision variables and relevant parameters.

Decision variables	
q_n, q_r	Manufacturing and remanufacturing quantities, $q_m = q_n + q_r$
τ	Abatement investment level
Relevant parameters	
p_n, p_r	Sales prices of unit new and remanufactured products, $p_n > p_r$
e_n, e_r	Emission quantities of unit new and remanufactured products, $e_n > e_r$
β	Consumer preference coefficient for remanufactured products, $0<\beta<1$
λ	Consumer low-carbon preference coefficient, $\lambda>0$
k	Abatement cost coefficient
μ	Environmental damage coefficient
p_e	Carbon price
δ	Industry emission benchmark coefficient under benchmarking
E_0	Initial carbon allowances under grandfathering
E_m	Manufacturer's total carbon emissions
π_m	Manufacturer's total profit
π_c	Consumer surplus
π_e	Environmental damage cost
π_g	Social welfare

products in a single period. With the popularity of environmental protection concepts, consumers tend to pay higher prices for low-carbon products. Moreover, as the advocate of low-carbon development, the government guides the manufacturer to carry out low-carbon activities by implementing the emissions trading policy. Free carbon allowances are allocated to the manufacturer by grandfathering or benchmarking. In our model, in addition to remanufacturing, the manufacturer could launch abatement investment activity to control carbon emissions. Thus, the manufacturer needs to jointly determine the abatement investment level and manufacturing/remanufacturing quantities to maximize its profit. For lucidity and simplicity, decision variables and relevant parameters involved in the models are shown in Table 1.

3.2 Assumptions

The following assumptions are provided to help understand our models:

Assumption 1. Consumers are heterogeneous in their willingness-to-pay for new products (σ) and remanufactured products ($\beta\sigma$), where β represents the consumer preference degree for remanufactured products and $0<\beta<1$. Then, assuming that consumers are willing to pay a higher price for the low-carbon product, the actual utility of purchasing a new product and a remanufactured product for rational consumers is $U_n(\sigma) = \sigma - p_n + \lambda\tau$ and $U_r(\sigma) = \beta\sigma - p_r + \lambda\tau$, respectively. It should be noted that λ represents consumers' low-carbon preference degree, and the stronger the consumer low-carbon preference, the higher the price consumers are willing to pay for low-carbon products. Consequently, the corresponding inverse demand functions can be obtained as follows: $p_n = 1 - q_n - \beta q_r + \lambda\tau$ and $p_r = \beta(1 - q_n - q_r) + \lambda\tau$. Similar assumptions can be found in the studies by Ji et al. (2017), Reimann et al. (2019), Ding et al. (2020), and Dong et al. (2021).

Assumption 2. Similar to Zhou et al. (2017), Ding et al. (2020), and Wang and Wang (2021), this paper also does not consider other manufacturing and remanufacturing costs in the models, which would help express the core issues. Thus, following Chen et al. (2020) and Chen and Chen (2021), the added values of new and remanufactured products are defined as $\Delta_1 = 1 - p_e e_n$ and $\Delta_2 = \beta - p_e e_r$, respectively, and $\Delta_1 > \Delta_2 > \beta\Delta_1$. In addition, for simplified expressions and convenient calculation, this paper also sets $M = \lambda + p_e e_n$ and $N = \lambda + p_e e_r$.

Assumption 3. The abatement activity can be regarded as a one-time investment, and the corresponding cost positively correlates with the abatement investment level. Following Qin et al. (2019), Ding et al. (2020), and Wang and Wang (2021), the abatement cost is assumed to be a quadratic function $k\tau^2/2$, where k represents the advancement and maturity of the manufacturer's abatement technologies. Without loss of generality, the more advanced and mature the abatement technologies, the lower the cost of the same abatement investment level.

Assumption 4. Under the emissions trading policy, two typical allocation rules of grandfathering and benchmarking are considered. Under grandfathering, the amount of free carbon allowances is mainly affected by the manufacturer's historical carbon emissions in the base year and, thus, is unchanged in a single period. However, total carbon allowances under benchmarking vary with the total output of both product types and are equal to the industry benchmark emissions intensity δ times the manufacturer's total output in the current period. Similar settings can be found in the studies by Ji et al. (2017) and Yang L.et al. (2020). The industry benchmark emission intensity means the government's emission control requirements for a certain industry. The higher the industry benchmark emission intensity, the lower the emission control requirements.

3.3 Profit maximization mathematical models for the manufacturer

In order to explore the effect of different allocation rules on the manufacturer's low-carbon activities, this subsection elaborates the construction of a mathematical model of profit maximization from a micro-operation level under two different conditions: the grandfathering allocation rule and the benchmarking allocation rule. Under the grandfathering case, total free carbon allowances for the manufacturer are assumed to be the constant E_0 and have no relation to the total output in the current period. However, as mentioned previously, total free carbon allowances under the benchmarking case are dynamic and are equal to the industry benchmark emission intensity δ times the total output in the current period. Furthermore, a comparative analysis is presented to clarify which allocation rule is more variable for remanufacturing and/or abatement investment decisions.

3.3.1 Grandfathering case

Under grandfathering, the manufacturer obtains free carbon allowances on the basis of historical carbon emissions in the base year after carbon verification (Sadegheih, 2011). Then, in addition to the carbon allowances allocated by the policy-maker and bought from carbon markets, the manufacturer could achieve carbon savings through low-carbon activities such as remanufacturing and abatement investments. Thus, according to the aforementioned problem description and assumptions, the manufacturer's profit function under grandfathering is as follows:

$$\pi_m^G = (1 - q_n - \beta q_r + \lambda\tau)q_n + [\beta(1 - q_n - q_r) + \lambda\tau]q_r - p_e[(e_n q_n + e_r q_r)(1 - \tau) - E_0] - \frac{1}{2}k\tau^2, \tag{1}$$

where the first and second terms represent the sales revenue of new and remanufactured products, respectively; the third term represents the cost or benefits from emission trading; and the last term denotes the manufacturer's total abatement cost.

Lemma 1. For a given τ, the manufacturer's profit function π_m under grandfathering is jointly concave with respect to q_n and q_r, and optimal manufacturing and remanufacturing quantities can be expressed as $q_n^G = \frac{(\Delta_1-\Delta_2)+(M-N)\tau}{2(1-\beta)}$ and $q_r^G = \frac{(\Delta_2-\beta\Delta_1)-(\beta M-N)\tau}{2\beta(1-\beta)}$, respectively.

Proof. See Appendix A.

Lemma 2. Under the condition of abatement investment and production integration decisions, the manufacturer's profit function π_m under grandfathering is jointly concave with respect to τ, q_n, and q_r, and the optimal abatement investment level and manufacturing and remanufacturing quantities can be expressed as follows, where $k > k_1$.

$$\tau_m^{G*} = \frac{\beta M(\Delta_1 - \Delta_2) + N(\Delta_2 - \beta\Delta_1)}{2k\beta(1-\beta) - (\beta M^2 + N^2 - 2\beta MN)},$$

$$q_n^{G*} = \frac{2k\beta(\Delta_1 - \Delta_2) + MN\cdot\Delta_2 - N^2\cdot\Delta_1}{2[2k\beta(1-\beta) - (\beta M^2 + N^2 - 2\beta MN)]},$$

$$q_r^{G'} = \frac{2k(\Delta_2 - \beta\Delta_1) + MN\cdot\Delta_1 - M^2\cdot\Delta_2}{2[2k\beta(1-\beta) - (\beta M^2 + N^2 - 2\beta MN)]}.$$

Proof. See Appendix A.

According to lemma 1 and lemma 2, the manufacturer's abatement investment and production decisions are not affected by the initial carbon allowances but are mainly affected by the carbon price determined by carbon markets. Thus, under grandfathering, the policy-maker cannot promote low-carbon investments and adjust production quantities in a single period by determining the amount of free carbon allowances. Meanwhile, grandfathering is even less effective in controlling the manufacturer's total carbon emissions, which is consistent with the results of most existing studies.

Proposition 1. Under grandfathering: (1) $\frac{\partial\tau_m^{G*}}{\partial k} < 0$; (2) $\frac{\partial q_n^{G*}}{\partial k} < 0$; (3) if $\beta M > N$, then $\frac{\partial q_r^{G*}}{\partial k} > 0$, otherwise, $\frac{\partial q_r^{G*}}{\partial k} < 0$.

Proof. See Appendix A.

Proposition 1 implies that the manufacturer will always reduce the abatement cost by decreasing the abatement investment level as the abatement cost coefficient k increases. Consequently, the manufacturer will decrease the manufacturing quantity to reduce the emission trading cost. However, when the consumer preference coefficient for remanufactured products *ß* is higher, the manufacturer's remanufacturing quantity increases as k increases. Otherwise, the manufacturer will also reduce the remanufacturing quantity. Similar results will be obtained under the benchmarking case, so we will not repeat them.

Proposition 2. Under grandfathering: (1) $\frac{\partial \tau_m^{G*}}{\partial \lambda} > 0$; (2) $\frac{\partial q_n^{G*}}{\partial \lambda} > 0$; (3) if $\beta M < N$, then $\frac{\partial q_r^{G*}}{\partial \lambda} > 0$; if $\beta M > N$, there exist three cases: (i) when k satisfies $k_1 < k < k_3 < k_2$, if $\frac{\Delta_1}{\Delta_2} < \frac{H_2}{H_1}$, then $\frac{\partial q_r^{G*}}{\partial \lambda} > 0$, otherwise $\frac{\partial q_r^{G*}}{\partial \lambda} < 0$; (ii) when k satisfies $k_1 < k_3 < k < k_2$, then $\frac{\partial q_r^{G*}}{\partial \lambda} < 0$; (iii) when k satisfies $k_1 < k_3 < k_2 < k$, if $\frac{\Delta_1}{\Delta_2} > \frac{H_2}{H_1}$, then $\frac{\partial q_r^{G*}}{\partial \lambda} > 0$, otherwise $\frac{\partial q_r^{G*}}{\partial \lambda} < 0$.

Proof. See Appendix A.

Proposition 2 denotes that, to increase product demand or reduce the emission trading cost, the manufacturer would always promote its abatement investment level as the consumer low-carbon preference coefficient λ increases. Correspondingly, when consumer low-carbon preference is stronger (namely, $\beta M < N$), the production quantities of both product types increase as λ increases. However, when consumer low-carbon preference is weaker (namely, $\beta M > N$), the manufacturing quantity increases as λ increases. Meanwhile, the changing trend of the remanufacturing quantity mainly depends on the abatement cost coefficient and the added value ratio of new and remanufactured products. Similar results will also be obtained under the benchmarking case, so we will not repeat them.

3.3.2 Benchmarking case

Under benchmarking, the manufacturer obtains total free carbon allowances based on the industry benchmark emission intensity and total output after carbon verification (Yang L.et al., 2020). To maximize the profit, the manufacturer needs to determine the abatement investment level and manufacturing/remanufacturing quantities in a single period. Therefore, according to the aforementioned problem description and assumptions, the manufacturer's profit function under benchmarking is as follows:

$$\pi_2^B = (1 - q_n - \beta q_r + \lambda\tau)q_n + [\beta(1 - q_n - q_r) + \lambda\tau]q_r - p_e[(e_n q_n + e_r q_r)(1 - \tau) - \delta(q_n + q_r)] - \frac{1}{2}k\tau^2, \tag{2}$$

where $\delta(q_n + q_r)$ represents total free carbon allowances obtained by the manufacturer under benchmarking.

Lemma 3. For a given τ, the manufacturer's profit function π_m under benchmarking is jointly concave with respect to q_n and q_r, and optimal manufacturing and remanufacturing quantities can be expressed as $q_n^B = \frac{(\Delta_1 - \Delta_2) + (M - N)\tau}{2(1-\beta)}$ and $q_r^B = \frac{(\Delta_2 - \beta\Delta_1) - (\beta M - N)\tau + (1-\beta)\delta p_e}{2\beta(1-\beta)}$, respectively.

Proof. See Appendix A.

Lemma 4. Under the condition of abatement investment and production integration decisions, the manufacturer's profit function π_m under benchmarking is jointly concave with respect to τ, q_n, and q_r, and the optimal abatement investment level and manufacturing and remanufacturing quantities can be expressed as follows, where $k > k_1$.

$$\tau_m^{B*} = \frac{\beta M(\Delta_1 - \Delta_2) + N(\Delta_2 - \beta\Delta_1) + N(1-\beta)\delta p_e}{2k\beta(1-\beta) - (\beta M^2 + N^2 - 2\beta MN)},$$

$$q_n^{B*} = \frac{2k\beta(\Delta_1 - \Delta_2) + MN \cdot \Delta_2 - N^2 \cdot \Delta_1 + N(M - N)\delta p_e}{2[2k\beta(1-\beta) - (\beta M^2 + N^2 - 2\beta MN)]},$$

$$q_r^{B'} = \frac{2k(\Delta_2 - \beta\Delta_1) + MN \cdot \Delta_1 - M^2 \cdot \Delta_2 + [2k(1-\beta) - M(M - N)]\delta p_e}{2[2k\beta(1-\beta) - (\beta M^2 + N^2 - 2\beta MN)]}.$$

Proof. See Appendix A.

According to lemma 3 and lemma 4, the manufacturer's abatement investment and production decisions under benchmarking are affected by the industry emission benchmark coefficient and carbon price. Thus, under benchmarking, the policy-maker can promote the abatement investment level and adjust production quantities in a single period by determining the industry emission benchmark coefficient. Consequently, benchmarking can achieve a controlling effect on the manufacturer's total carbon emissions.

Proposition 3. Under the benchmarking: (1) $\frac{\partial \tau_m^{B*}}{\partial \delta} > 0$; (2) $\frac{\partial q_n^{B*}}{\partial \delta} > 0$; (3) if $\beta M < N$, then $\frac{\partial q_r^{B*}}{\partial \delta} > 0$; if $\beta M > N$, there exists $\frac{\partial q_r^{B*}}{\partial \delta} < 0$ when k satisfies $k_1 < k < k_3$ and $\frac{\partial q_r^{B*}}{\partial \delta} > 0$ when k satisfies $k_1 < k_3 < k$.

Proof. See Appendix A.

Proposition 3 indicates that an increasing industry emission benchmark coefficient δ can always increase the manufacturing quantity since new products are more profitable. However, whether the increasing δ is beneficial to remanufacturing activities also depends on the consumer low-carbon preference coefficient λ and the abatement cost coefficient k. Concretely, if consumer low-carbon preference is stronger, the remanufacturing quantity will increase as δ increases. Otherwise, the increasing δ would increase the remanufacturing quantity only when k is relatively high. At this time, a higher k will result in a lower total output and an increment in new products. More importantly, regardless of how remanufacturing quantity changes, a higher manufacturing quantity can always increase the total carbon emissions or emission trading cost. Therefore, as δ increases, the manufacturer will enhance the abatement investment level, which reduces unit carbon emissions of both product types and thereby improves the manufacturer's total profit.

3.3.3 Comparative analysis

First, Δq_r is defined as the difference between remanufacturing quantities under grandfathering and benchmarking. When the abatement investment level is given, corollary 1 can be easily obtained as follows:

Corollary 1. For a given τ, there always exist (1) $q_n^G = q_n^B$ and $q_r^G < q_r^B$; (2) $\frac{\partial \Delta q_r}{\partial p_e} > 0$ and $\frac{\partial \Delta q_r}{\partial \beta} < 0$.

Proof. See Appendix A.

Corollary 1 shows that under a given abatement investment level, benchmarking is more beneficial for remanufacturing activities. Moreover, this advantage would become more apparent as carbon price p_e increases or the consumer preference coefficient for remanufactured products β decreases, that is to say, the harsher the remanufacturing environment, the more apparent the advantage in promoting remanufacturing activities under benchmarking. The main reason is that the increase in the production quantity of each product type under benchmarking will bring higher initial free carbon allowances. This would make it possible for the manufacturer to further increase the remanufacturing quantity and thereby decrease the higher emission trading cost caused by the increased total production quantity or carbon price. Therefore, when the manufacturer's abatement investment level is given, the policy-maker should adopt the benchmarking allocation rule to better promote remanufacturing activities.

Then, $\Delta\tau_m^*$, Δq_n^*, Δq_r^*, and Δq_m^* are defined as the difference between abatement investment levels, manufacturing quantities, remanufacturing quantities, and total production quantities, respectively, under grandfathering and benchmarking. Then, when the manufacturer needs to comprehensively determine abatement investment levels and manufacturing/ remanufacturing quantities, the following three corollaries can be easily obtained.

Corollary 2. Under the condition of abatement investment and production integration decisions, there always exists $\tau_m^{G*} < \tau_m^{B*}$.

Proof. See Appendix A.

Corollary 2 shows that compared with grandfathering, benchmarking can better promote the manufacturer's abatement investment level. This is because as an allocation rule to control carbon emissions on the aggregate level, the initial carbon allowances under grandfathering do not affect the manufacturer's abatement investment decision. The abatement investment decision is mainly affected by carbon price. Under benchmarking, the initial carbon allowances mainly depend on the industry benchmark emission intensity and the total current output. Then, when the total market share of low-carbon products is relatively high as shown in corollary 3, the manufacturer must raise the abatement investment level to avoid excessive emission trading cost from damaging its total profit. Therefore, benchmarking is a better allocation rule to facilitate the manufacturer's abatement investment than grandfathering.

Corollary 3. Under the condition of abatement investment and production integration decisions, there always exist (1) $q_n^{G*} < q_n^{B*}$; (2) if $\beta M < N$, then $q_r^{G*} < q_r^{B*}$; if $\beta M > N$, then $q_r^{G*} > q_r^{B*}$ when k satisfies $k_1 < k < k_3$ and $q_r^{G*} < q_r^{B*}$ when k satisfies $k_1 < k_3 < k$; (3) $q_n^{G*} + q_r^{G*} < q_n^{B*} + q_r^{B*}$.

Proof. See Appendix A.

Corollary 3 implies that under different allocation rules, a higher abatement investment level is always accompanied by higher manufacturing quantity and total production quantity. This also shows that benchmarking can better improve the market share of low-carbon products while promoting the manufacturer's abatement investment level. However, which allocation rule would induce a higher remanufacturing quantity mainly depends on the consumer low-carbon preference coefficient λ and abatement cost coefficient k. When λ is high (namely, $\beta M < N$), the remanufacturing quantity under benchmarking would be higher. If λ is low, benchmarking is more conducive to promoting remanufacturing activities only when k is relatively high. This is mainly because, considering the higher emission trading cost, the manufacturer would produce more remanufactured products with carbon-saving advantages when k is higher. Then, benchmarking shows a diminishing advantage in manufacturing activities but a growing advantage in remanufacturing activities as λ increases. Conversely, when k is lower than a certain threshold, benchmarking shows a stronger advantage in manufacturing activities, while the corresponding remanufacturing quantity is lower. Therefore, a stronger consumer low-carbon preference is more beneficial to benchmarking in promoting remanufacturing activities. However, if the consumer low-carbon preference is relatively weak, the policy-maker should adopt the benchmarking allocation rule to better promote remanufacturing activities with a higher abatement cost. Otherwise, the grandfathering allocation rule would be implemented with a lower abatement cost.

Corollary 4. Under the condition of abatement investment and production integration decisions, there always exist:

(1) $\frac{\partial \Delta\tau_m^*}{\partial k} < 0$; $\frac{\partial \Delta q_n^*}{\partial k} < 0$; if $\beta M < N$, $\frac{\partial \Delta q_r^*}{\partial k} < 0$, otherwise, $\frac{\partial \Delta q_r^*}{\partial k} > 0$; $\frac{\partial \Delta q_m^*}{\partial k} < 0$;

(2) $\frac{\partial \Delta\tau_m^*}{\partial \lambda} > 0$; $\frac{\partial \Delta q_n^*}{\partial \lambda} > 0$; if $\beta < \frac{2N}{M+N}$, then $\frac{\partial \Delta q_r^*}{\partial \lambda} > 0$ when k satisfies $k > \frac{(M-N)(2MN-\beta M^2-N^2)}{2(1-\beta)(2N-\beta M-\beta N)}$, otherwise, $\frac{\partial \Delta q_r^*}{\partial \lambda} < 0$; if $\beta > \frac{2N}{M+N}$, then $\frac{\partial \Delta q_r^*}{\partial \lambda} > 0$ when k satisfies $k < \frac{(M-N)(\beta M^2+N^2-2MN)}{2(1-\beta)(\beta M+\beta N-2N)}$, otherwise, $\frac{\partial \Delta q_r^*}{\partial \lambda} < 0$; $\frac{\partial \Delta q_m^*}{\partial \lambda} > 0$.

Proof. See Appendix A.

Corollary 4 shows that as the abatement cost coefficient k decreases or the consumer low-carbon preference coefficient λ increases, the advantages in abatement investment, manufacturing activity, and total production quantity under benchmarking are all expanding. This is mainly because changes in the aforementioned variables are more sensitive to k or λ. However, the sensitivity of the remanufacturing decision to k or λ under each allocation rule mainly depends on which allocation rule has an advantage in remanufacturing activities, the changing trend of the remanufacturing quantity to them, and

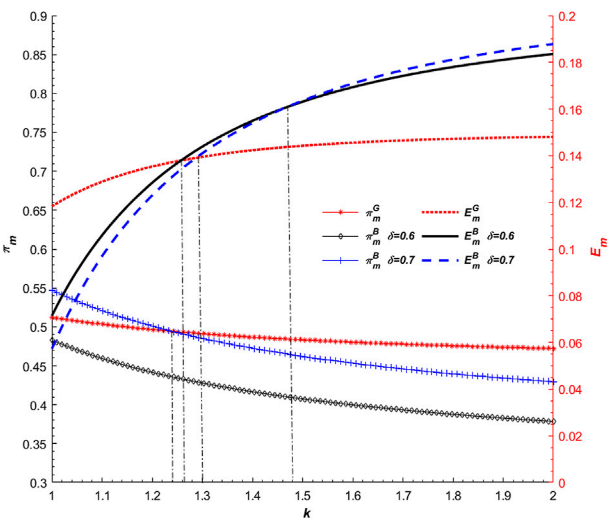

FIGURE 1
Effects of δ on total profit and total carbon emissions.

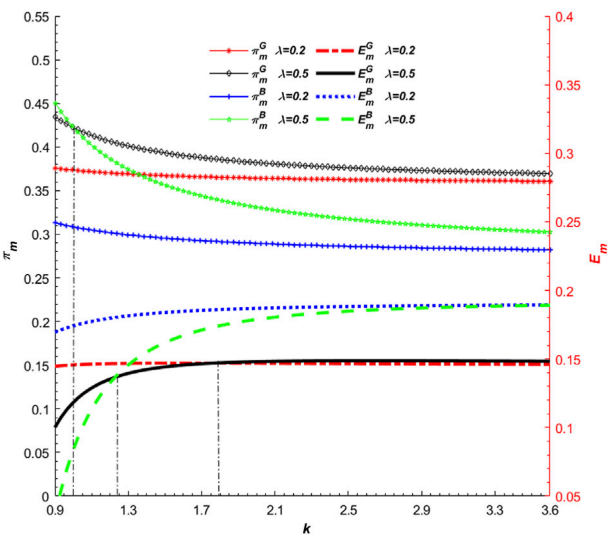

FIGURE 2
Effects of λ on total profit and total carbon emissions.

the carbon price. This also indicates that, as k decreases or λ increases, how the advantage in remanufacturing activities changes under each allocation rule needs to comprehensively consider other factors.

4 Numerical analysis and discussion

This section further explores the effect on different performance targets, such as total profit, total carbon emissions, consumer surplus, and social welfare, through numerical analysis. First, $0<\beta<1$, which indicates that consumers have a lower willingness-to-pay for remanufactured products, so we considered $\beta = 0.65$. To reflect carbon savings of active remanufacturing, the unit new product's carbon emissions are set clearly higher ($e_n = 0.6$), and that of the unit remanufactured product is lower ($e_r = 0.3$). Then, combining the data obtained from investigating actual remanufacturers in China and actual practice, the other parameters involved in the model are set as follows: $p_e = 0.6$, $E_0 = 0.55$, and $\mu = 0.2$. Finally, specific results will be presented in the following figures.

4.1 Effects on total profit and total carbon emissions

First, this subsection shows the value of $\lambda = 0.5$ and mainly discusses the effect on the manufacturer's total profit and total carbon emissions. As shown in Figure 1, under each allocation rule, the manufacturer's total profit decreases with the increase of the abatement cost coefficient k, which is mainly because manufacturing/remanufacturing quantities decrease as k increases. Moreover, the total profit positively correlates with the industry emission benchmark coefficient δ under benchmarking. Thus, when initial carbon allowances E_0 remain unchanged under grandfathering, benchmarking gradually shows more advantages in the total profit as δ increases. However, as k increases, the advantage (or disadvantage) in the total profit under benchmarking will become weaker (or more apparent) than under grandfathering.

Furthermore, Figure 1 shows that the manufacturer's total carbon emissions increase with the increase of the abatement cost coefficient k under each allocation rule. This is mainly because a higher abatement cost coefficient would result in a lower abatement investment level. More interestingly, the correlation between the total carbon emissions and the industry emission benchmark coefficient under benchmarking depends on the abatement cost coefficient. Specifically, the total carbon emissions have a negative correlation with δ when k is low (k<1.48) and a positive correlation with δ when k is high (k>1.48). A possible explanation is that, when k is relatively low, a higher abatement investment level will lead to lower total carbon emissions. This indicates that although the increasing δ can always bring a higher total profit to the manufacturer, it is at the cost of higher carbon emissions when k is high. Therefore, a looser benchmarking allocation rule would be beneficial to both the total profit and the environment only when the abatement cost is low. Otherwise, the policy-maker should weigh the total profit and the environment further to determine the industry emission benchmark coefficient. In addition, which allocation rule is more beneficial to the environment also depends on the abatement cost coefficient. As k increases, the advantage (or disadvantage) in emission control under benchmarking will also become weaker (or more apparent) than under grandfathering. Consequentially, both in terms of the total profit and the environment, benchmarking is more beneficial when the abatement cost is lower. Otherwise, grandfathering would be more viable.

Then, this subsection shows the value of δ = 0.5 and explores the effect on the manufacturer's total profit and total carbon emissions. As shown in Figure 2, the manufacturer's total profit under each allocation rule positively correlates with the consumer low-carbon preference coefficient λ. However, the higher the abatement cost coefficient k, the weaker the advantage in the total profit caused by the higher λ. Moreover, compared with grandfathering, the equal change in λ would bring a larger increment in the total profit under benchmarking. This is mainly because the increasing λ can not only enhance the product demand but also increase initial free carbon allowances, which could improve the emission trading revenue or reduce emission trading cost. More importantly, Figure 2 shows that the increasing λ would further weaken the disadvantage or enhance the advantage in the total profit under benchmarking. Otherwise, grandfathering is more beneficial to the total profit when the consumer low-carbon preference is relatively weak.

Furthermore, under each allocation rule, a higher consumer low-carbon preference coefficient λ would abnormally lead to lower total carbon emissions only when the abatement cost coefficient k is lower than a certain threshold. Relatively speaking, the threshold of k mentioned previously under benchmarking (k = 3.6) is much greater than that under grandfathering (k = 1.78). It shows that benchmarking can better ensure that the increasing λ is beneficial to both the profit and the environment. However, under grandfathering, the greater total profit caused by a higher λ is more often at the cost of heavy carbon emissions. Finally, when the consumer low-carbon preference is relatively weak, grandfathering is more viable to the environment. Otherwise, which allocation rule is more beneficial to the environment also depends on the abatement cost coefficient. As mentioned previously, a lower abatement cost is more conducive to show the advantage of benchmarking in the environment. This also indicates that the increasing λ is more beneficial to reflect the advantage of benchmarking in the environment. In summary, when the consumer low-carbon preference coefficient is relatively strong, benchmarking is more beneficial for manufacturers to perform better both in terms of the total profit and the environment. Otherwise, grandfathering would be more viable.

4.2 Effects on consumer surplus and social welfare

This subsection mainly elaborates the effect on consumer surplus and social welfare. Following Ding et al. (2020) and Wang and Wang (2021), the consumer surplus is shown as follows: $\pi_c^j = \frac{q_n^j 2+\beta q_r^j 2+2\beta q_n^j q_r^j}{2}$, $j = G, B$. Correspondingly, referring to Yenipazarli (2016) and Wang and Wang (2021), social welfare is defined as the sum of the manufacturer's total profit and consumer surplus minus environmental damage cost. Then, the social welfare function is shown as follows: $\pi_g^j = \pi_m^j + \pi_c^j - \pi_e^j = \pi_m^j + \frac{q_n^j 2 + \beta q_r^j 2 + 2\beta q_n^j q_r^j}{2} - \mu[(e_n q_n^j + e_r q_r^j)(1 - \tau_m^j)]$, $j = G, B$.

Next, we set $\lambda = 0.5$, and the results are shown in Figure 3. Figure 3A shows that the consumer surplus under benchmarking shows a positive correlation with the industry emission benchmark coefficient δ. Consequently, which allocation rule is more beneficial to consumer surplus mainly depends on the industry emission benchmark coefficient. Moreover, as shown in Figures 3A,B, higher δ would ultimately induce higher social welfare due to the higher total profit and consumer surplus. Similarly, which allocation rule is more beneficial to social welfare also mainly depends on the industry emission benchmark coefficient. However, when δ is unchanged, a higher abatement cost coefficient k would make the disadvantage (or advantage) of grandfathering in social welfare even weaker (or even stronger). This is mainly because, as mentioned previously, grandfathering is more beneficial to the total profit and the environment when the abatement cost is lower. Finally, taking δ = 0.6 as an example, it can be found that benchmarking is not necessarily more beneficial to the manufacturer's total profit and the environment but always shows more apparent advantages in consumer surplus and social welfare. Therefore, from the perspective of consumers and policy-makers, benchmarking may be more conducive to achieving the corresponding performance target.

Finally, we set δ = 0.5, and the results are shown in Figure 4. It can be observed that, under the aforementioned two allocation rules, both consumer surplus and social welfare show positive correlations with the consumer low-carbon preference coefficient λ. However, as the higher abatement cost coefficient k increases, the corresponding increments in consumer surplus and social welfare caused by increasing λ would reduce. In addition, from the perspective of consumers, benchmarking always shows apparent advantages compared with grandfathering, as shown in Figure 4A. A possible explanation is that benchmarking can better improve the market share of low-carbon products as shown in corollary 3. From the perspective of policy-makers, which allocation rule is more viable for social welfare mainly depends on λ and k. Specifically, grandfathering shows an apparent advantage

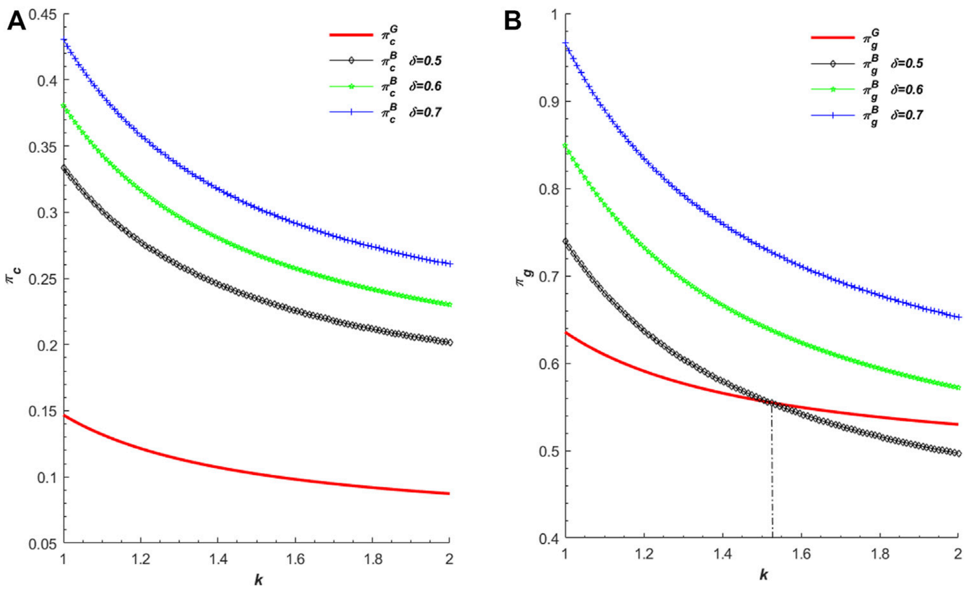

FIGURE 3
Effects of δ on **(A)** consumer surplus and **(B)** social welfare.

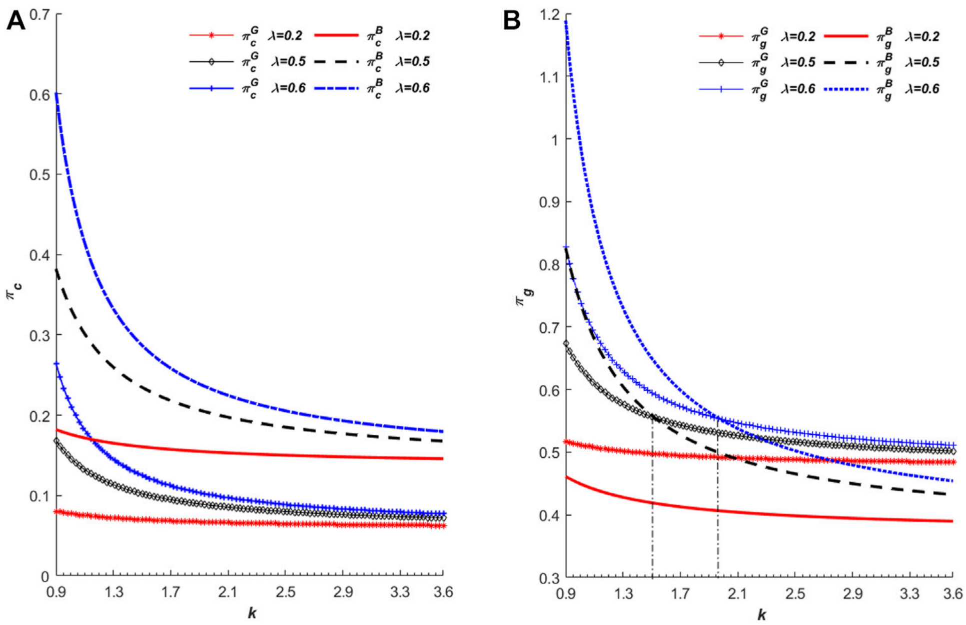

FIGURE 4
Effects of λ on **(A)** consumer surplus and **(B)** social welfare.

in social welfare when λ is low ($\lambda = 0.2$). When λ is high ($\lambda = 0.5$ or 0.6), grandfathering is more advantageous only when k exceeds a certain threshold. More interestingly, the threshold value of k (k = 1.92) with a higher consumer low-carbon preference coefficient ($\lambda = 0.6$) is greater than that (k = 1.46) with lower consumer low-carbon preference coefficient ($\lambda = 0.5$), which is mainly because, as mentioned previously, a higher λ is more beneficial to reflect the advantages of benchmarking in the total profit and the environment. Correspondingly, a higher k is more beneficial to reflect the advantages of grandfathering in the total profit and the environment. Eventually, taking social welfare as a performance target, the stronger consumer low-carbon preference or the lower abatement cost may weaken the disadvantage or enhance the advantage of benchmarking. Conversely, the policy-maker may be more inclined to adopt the grandfathering allocation rule in a situation with weaker consumer low-carbon preference or higher abatement cost.

5 Conclusion

Focusing on different carbon allowance allocation rules of grandfathering and benchmarking under the emissions trading policy, this study mainly explored a monopolistic manufacturer's abatement investment and manufacturing/remanufacturing decisions in a single period by maximizing the total profit. Meanwhile, the effects of grandfathering and benchmarking on decision variables and performance targets (e.g., total profit, total carbon emissions, consumer surplus, and social welfare) are analyzed through theoretical and numerical analyses. Finally, some managerial insights and policy implications are provided for the manufacturer's low-carbon activities and the policy-makers' policy design, respectively.

First, under grandfathering, the policy-maker cannot adjust manufacturers' abatement investment and manufacturing/remanufacturing decisions by the administrative measure. However, benchmarking could affect manufacturers' low-carbon operations through administrative measures (e.g., the industry emission benchmark coefficient) and economic measures (e.g., the carbon price). In addition, under benchmarking, the increasing industry emission benchmark coefficient can always promote manufacturers' abatement investment levels. It should be noted that only in a situation with stronger consumer low-carbon preference can the rising industry emission benchmark coefficient also always increase manufacturers' remanufacturing quantities. Eventually, the higher the industry emission benchmark coefficient, the greater the total profit, consumer surplus, and social welfare. The difference is that the correlation between the industry emission benchmark coefficient and the environment mainly depends on the abatement cost coefficient. Only when the abatement cost is relatively low will the industry emission benchmark coefficient be higher and the total carbon emissions be lower. Otherwise, the increment in the total profit caused by the increasing industry emission benchmark coefficient would be at the cost of heavy emissions. Therefore, for policy-makers to better achieve the environmental performance target, a higher industry emission benchmark coefficient should be provided for manufacturers with lower abatement costs; on the contrary, a tightened allocation rule of benchmarking should be implemented. For manufacturers, it is more helpful to achieve a win–win goal of economic and environmental benefits by reducing the abatement cost under benchmarking.

Second, under a given abatement investment level, benchmarking is more viable for manufacturers' remanufacturing activities than grandfathering. Additionally, the harsher the remanufacturing environment (e.g., higher carbon price and lower willingness-to-pay for remanufactured products), the more apparent the advantage in promoting remanufacturing activities under benchmarking. Furthermore, under the condition of integrating abatement investment and manufacturing/remanufacturing decisions, benchmarking is more viable for manufacturers' abatement investment activities than grandfathering. Meanwhile, a stronger consumer low-carbon preference or lower abatement cost would make this advantage more apparent. Similarly, only in a situation with a stronger consumer low-carbon preference is benchmarking more viable for manufacturers' remanufacturing activities. Correspondingly, the higher the consumer low-carbon preference or the lower the abatement cost, the more favorable benchmarking is to achieve each performance target (e.g., total profit, emission control, consumer surplus, and social welfare). Therefore, for policy-makers, benchmarking should be implemented to better promote manufacturers' abatement investment activities. More importantly, in a situation with a stronger consumer low-carbon preference or lower abatement cost, benchmarking may be more beneficial to manufacturers' remanufacturing activities and each performance target. Otherwise, grandfathering would be more viable. For manufacturers, under each allocation rule, the lower emission reduction cost or the stronger low-carbon preference will help them reasonably respond to changes in the market environment or policy environment and better achieve a win–win goal of economic and environmental benefits.

Finally, our study can be extended in a few ways for future research. For instance, the issue studied in this work can be extended to two-period or multi-period, and the volatility in the carbon price will be considered. Additionally, the policy-maker's decision-making process can be embedded, and more carbon allowance allocation rules should be modeled.

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

ZW and YW contributed to conceptualization, methodology, and writing—original draft. ZW contributed to funding acquisition, writing—review and editing, and supervision. FW and YW contributed to literature sorting, formal analysis, and software.

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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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Appendix A:

Proof of Lemma 1. According to Eq. 1, the first derivation of the manufacturer's profit π_m with respect to q_n and q_r is shown as follows:

$$\frac{\partial \pi_m^G}{\partial q_n} = 1 - 2q_n - 2\beta q_r + \lambda\tau - p_e e_n(1-\tau) = 0,$$
$$\frac{\partial \pi_m^G}{\partial q_r} = \beta - 2\beta q_n - 2\beta q_r + \lambda\tau - p_e e_r(1-\tau) = 0.$$

Then, the manufacturer's optimal manufacturing and remanufacturing quantities are

$$q_n^G = \frac{(\Delta_1 - \Delta_2) + (M-N)\tau}{2(1-\beta)},$$
$$q_r^G = \frac{(\Delta_2 - \beta\Delta_1) - (\beta M - N)\tau}{2\beta(1-\beta)}.$$

Therefore, lemma 1 is proved.

Proof of Lemma 2. According to Eq. 1, the first derivation of the manufacturer's profit π_m with respect to τ is shown as follows:

$$\frac{\partial \pi_m^G}{\partial \tau} = (\lambda + p_e e_n)q_n + (\lambda + p_e e_r)q_r - k\tau = 0.$$

Substituting q_n^G and q_r^G into the aforementioned formula, we obtain

$$\tau_m^{G*} = \frac{\beta M(\Delta_1 - \Delta_2) + N(\Delta_2 - \beta\Delta_1)}{2k\beta(1-\beta) - (\beta M^2 + N^2 - 2\beta MN)},$$
$$q_n^{G*} = \frac{2k\beta(\Delta_1 - \Delta_2) + MN\cdot\Delta_2 - N^2\cdot\Delta_1}{2[2k\beta(1-\beta) - (\beta M^2 + N^2 - 2\beta MN)]},$$
$$q_r^{G'} = \frac{2k(\Delta_2 - \beta\Delta_1) + MN\cdot\Delta_1 - M^2\cdot\Delta_2}{2[2k\beta(1-\beta) - (\beta M^2 + N^2 - 2\beta MN)]},$$
$$q_m^{G*} = q_n^{G*} + q_r^{G'} = \frac{2k(1-\beta)\Delta_2 + (M-N)(N\cdot\Delta_1 - M\cdot\Delta_2)}{2[2k\beta(1-\beta) - (\beta M^2 + N^2 - 2\beta MN)]}.$$

In order to ensure that decision variables are not negative, then

$$2k\beta(1-\beta) - (\beta M^2 + N^2 - 2\beta MN) > 0 \Rightarrow k > \frac{\beta M^2 + N^2 - 2\beta MN}{2\beta(1-\beta)} = k_1.$$

Therefore, lemma 2 is proved.

Proof of Proposition 1. According to expressions of τ_m^{G*}, q_n^{G*}, and q_r^{G*}, we can obtain

$$\frac{\partial \tau_m^{G*}}{\partial k} = -\frac{2\beta(1-\beta)[\beta M(\Delta_1 - \Delta_2) + N(\Delta_2 - \beta\Delta_1)]}{[2k\beta(1-\beta) - (\beta M^2 + N^2 - 2\beta MN)]^2}.$$

Since $\Delta_1 > \Delta_2 > \beta\Delta_1$, we can obtain $\frac{\partial \tau_m^{G*}}{\partial k} < 0$.

$$\frac{\partial q_n^{G*}}{\partial k} = -\frac{4\beta(M-N)[\beta(M-N)\Delta_1 - (\beta M - N)\Delta_2]}{\{2[2k\beta(1-\beta) - (\beta M^2 + N^2 - 2\beta MN)]\}^2}.$$

Moreover, since

$$\Delta_1 > \Delta_2$$

, then

$$\beta(M-N)\Delta_1 - (\beta M - N)\Delta_2 > [\beta(M-N) - (\beta M - N)]\Delta_2 = N(1-\beta) > 0.$$

Thus, $\frac{\partial q_n^{G*}}{\partial k} < 0$.

$$\frac{\partial q_r^{G'}}{\partial k} = -\frac{4(\beta M - N)[(\beta M - N)\Delta_2 - \beta(M-N)\Delta_1]}{\{2[2k\beta(1-\beta) - (\beta M^2 + N^2 - 2\beta MN)]\}^2}.$$

Since $(\beta M - N)\Delta_2 - \beta(M-N)\Delta_1 < 0$, we can obtain that if $\beta M > N$, then $\frac{\partial q_r^{G*}}{\partial k} > 0$, otherwise, $\frac{\partial q_r^{G*}}{\partial k} < 0$.

Therefore, proposition 1 is proved.

Proof of Proposition 2. According to expressions of τ_m^{G*}, q_n^{G*}, and q_r^{G*}, we can obtain

$$\frac{\partial \tau_m^{G*}}{\partial \lambda} = \frac{\Delta_2(1-\beta)[2k\beta(1-\beta) - (\beta M^2 + N^2 - 2\beta MN)] + 2N(1-\beta)[\beta M(\Delta_1 - \Delta_2) + N(\Delta_2 - \beta\Delta_1)]}{[2k\beta(1-\beta) - (\beta M^2 + N^2 - 2\beta MN)]^2}.$$

Since $\Delta_1 > \Delta_2 > \beta\Delta_1$, we can obtain $\frac{\partial \tau_m^{G*}}{\partial \lambda} > 0$.

$$\frac{\partial q_n^{G*}}{\partial \lambda} = \frac{(M-N)\{[4k\beta(1-\beta) - 2(\beta M^2 - N^2)]\Delta_2 + 4\beta N(M-N)\Delta_1\}}{\{2[2k\beta(1-\beta) - (\beta M^2 + N^2 - 2\beta MN)]\}^2}.$$

Since

$$\Delta_1 > \Delta_2$$

, then,

$$\begin{aligned}&[4k\beta(1-\beta) - 2(\beta M^2 - N^2)]\Delta_2 + 4\beta N(M-N)\Delta_1\\ &> [4k\beta(1-\beta) - 2(\beta M^2 - N^2) + 4\beta N(M-N)]\Delta_2\\ &> [2(\beta M^2 + N^2 - 2\beta MN) - 2(\beta M^2 - N^2) + 4\beta N(M-N)]\Delta_2\\ &= 4N^2(1-\beta)\Delta_2 > 0\end{aligned}.$$

Thus, $\frac{\partial q_n^{G*}}{\partial \lambda} > 0$.

$$\frac{\partial q_r^{G'}}{\partial \lambda} = \frac{(M-N)[4k\beta(1-\beta) - 2(\beta M^2 - N^2)]\Delta_1 - 2(\beta M - N)[4k(1-\beta) - 2M(M-N)]\Delta_2}{\{2[2k\beta(1-\beta) - (\beta M^2 + N^2 - 2\beta MN)]\}^2},$$

$$4k\beta(1-\beta) - 2(\beta M^2 - N^2) > 0 \Rightarrow k > \frac{\beta M^2 - N^2}{2\beta(1-\beta)} = k_2,$$

$$4k(1-\beta) - 2M(M-N) > 0 \Rightarrow k > \frac{M(M-N)}{2(1-\beta)} = k_3,$$

$$k_1 - k_2 = \frac{N(N-\beta M)}{\beta(1-\beta)},\ k_1 - k_3 = \frac{N(N-\beta M)}{2\beta(1-\beta)},\ k_3 - k_2 = \frac{N(N-\beta M)}{2\beta(1-\beta)}.$$

If $\beta M < N$, then $k_1 > k_3 > k_2$. There always exists $k > k_1$, so we have $k > k_3 > k_2$, namely, $H_1 > 0$ and $H_2 < 0$. Then, we can obtain $\frac{\partial q_r^{G*}}{\partial \lambda} > 0$.

If $\beta M > N$, then $k_1 < k_3 < k_2$. ① When k satisfies $k_1 < k < k_3 < k_2$, then $H_1 < 0$ and $H_2 < 0$. There always exists $\frac{\Delta_1}{\Delta_2} < \frac{H_2}{H_1}$, and we can obtain $\frac{\partial q_r^{G'}}{\partial \lambda} > 0$, otherwise, $\frac{\partial q_r^{G'}}{\partial \lambda} < 0$. ② When k satisfies $k_1 < k_3 < k < k_2$, then $H_1 < 0$ and $H_2 > 0$. Thus, we can obtain $\frac{\partial q_r^{G*}}{\partial \lambda} < 0$. ③ When k satisfies

$k_1 < k_3 < k_2 < k$, then $H_1 > 0$ and $H_2 < 0$. There always exists $\frac{\Delta_1}{\Delta_2} > \frac{H_2}{H_1}$, and we can obtain $\frac{\partial q_r^{G*}}{\partial \lambda} > 0$, otherwise $\frac{\partial q_r^{G*}}{\partial \lambda} < 0$. It needs to be further noted that $H_1 = (M - N)[4k\beta(1-\beta) - 2(\beta M^2 - N^2)]$ and $H_2 = 2(\beta M - N)[4k(1-\beta) - 2M(M-N)]$.

Therefore, proposition 2 is proved.

Proof of Lemma 3. According to Eq. 1, the first derivation of the manufacturer's profit π_m with respect to q_n and q_r is shown as follows:

$$\frac{\partial \pi_m^B}{\partial q_n} = 1 - 2q_n - 2\beta q_r + \lambda\tau - p_e e_n(1-\tau) + \delta p_e = 0,$$

$$\frac{\partial \pi_m^B}{\partial q_r} = \beta - 2\beta q_n - 2\beta q_r + \lambda\tau - p_e e_r(1-\tau) + \delta p_e = 0.$$

Then, the manufacturer's optimal manufacturing and remanufacturing quantities are

$$q_n^B = \frac{(\Delta_1 - \Delta_2) + (M-N)\tau}{2(1-\beta)},$$

$$q_r^B = \frac{(\Delta_2 - \beta\Delta_1) - (\beta M - N)\tau + (1-\beta)\delta p_e}{2\beta(1-\beta)}.$$

Therefore, lemma 3 is proved.

Proof of Lemma 4. According to Eq. 2, the first derivation of the manufacturer's profit π_m with respect to τ is shown as follows:

$$\frac{\partial \pi_m^B}{\partial \tau} = (\lambda + p_e e_n)q_n + (\lambda + p_e e_r)q_r - k\tau = 0.$$

Substituting q_n^B and q_r^B into the aforementioned formula, we can obtain

$$\tau_m^{B*} = \frac{\beta M(\Delta_1 - \Delta_2) + N(\Delta_2 - \beta\Delta_1) + N(1-\beta)\delta p_e}{2k\beta(1-\beta) - (\beta M^2 + N^2 - 2\beta MN)},$$

$$q_n^{B*} = \frac{2k\beta(\Delta_1 - \Delta_2) + MN\cdot\Delta_2 - N^2\cdot\Delta_1 + N(M-N)\delta p_e}{2[2k\beta(1-\beta) - (\beta M^2 + N^2 - 2\beta MN)]},$$

$$q_r^{B'} = \frac{2k(\Delta_2 - \beta\Delta_1) + MN\cdot\Delta_1 - M^2\cdot\Delta_2 + [2k(1-\beta) - M(M-N)]\delta p_e}{2[2k\beta(1-\beta) - (\beta M^2 + N^2 - 2\beta MN)]},$$

$$q_m^{B*} = q_n^{B'} + q_r^{B'} = \frac{2k(1-\beta)\Delta_2 + (M-N)(N\cdot\Delta_1 - M\cdot\Delta_2) + [2k(1-\beta) - (M-N)^2]\delta p_e}{2[2k\beta(1-\beta) - (\beta M^2 + N^2 - 2\beta MN)]}.$$

Similarly, in order to ensure that decision variables are not negative, then

$$2k\beta(1-\beta) - (\beta M^2 + N^2 - 2\beta MN) > 0$$
$$\Rightarrow k > \frac{\beta M^2 + N^2 - 2\beta MN}{2\beta(1-\beta)} = k_1$$

Therefore, lemma 4 is proved.

Proof of Proposition 3. According to expressions of τ_m^{B*}, q_n^{B*}, and q_r^{B*}, we can obtain

$$\frac{\partial \tau_m^{B*}}{\partial \delta} = \frac{N(1-\beta)p_e}{2k\beta(1-\beta) - (\beta M^2 + N^2 - 2\beta MN)}.$$

Since $k > k_1$, we can obtain $\frac{\partial \tau_m^{B*}}{\partial \delta} > 0$.

$$\frac{\partial q_n^{B*}}{\partial \delta} = \frac{N(M-N)p_e}{2[2k\beta(1-\beta) - (\beta M^2 + N^2 - 2\beta MN)]}.$$

Since $M > N$, we have $\frac{\partial q_n^{B*}}{\partial \delta} > 0$.

$$\frac{\partial q_r^{B'}}{\partial \delta} = \frac{[2k(1-\beta) - M(M-N)]p_e}{2[2k\beta(1-\beta) - (\beta M^2 + N^2 - 2\beta MN)]},$$

$$2k(1-\beta) - M(M-N) > 0 \Rightarrow k > \frac{M(M-N)}{2(1-\beta)} = k_3,$$

$$k_1 - k_3 = \frac{N(N - \beta M)}{2\beta(1-\beta)}.$$

If $\beta M < N$, then $k_1 > k_3$. Since $k > k_1$, there always exists $k > k_3$. Thus, we have $\frac{\partial q_r^{B*}}{\partial \delta} > 0$.

If $\beta M > N$, then $k_1 < k_3$. When $k_1 < k < k_3$, we have $\frac{\partial q_r^{B*}}{\partial \delta} < 0$; when $k_1 < k_3 < k$, we have $\frac{\partial q_r^{B*}}{\partial \delta} > 0$.

Therefore, proposition 3 is proved.

Proof of Corollary 1. According to expressions of q_r^G and q_r^B, we can obtain

$$\Delta q_r = \frac{(\Delta_2 - \beta\Delta_1) - (\beta M - N)\tau + (1-\beta)\delta p_e}{2\beta(1-\beta)} - \frac{(\Delta_2 - \beta\Delta_1) - (\beta M - N)\tau}{2\beta(1-\beta)} = \frac{\delta p_e}{2\beta} > 0.$$

Obviously, Δq_r will increase as the carbon price p_e increases or the consumer preference coefficient ß decreases.

Therefore, corollary 1 is proved.

Proof of Corollary 2. According to expressions of τ_m^{G*} and τ_m^{B*}, we can obtain

$$\Delta\tau_m^* = \tau_m^{B*} - \tau_m^{G*} = \frac{N(1-\beta)\delta p_e}{2k\beta(1-\beta) - (\beta M^2 + N^2 - 2\beta MN)} > 0.$$

Therefore, corollary 2 is proved.

Proof of Corollary 3. According to expressions of q_n^{G*}, q_r^{G*}, q_n^{B*}, and q_r^{B*}, we can obtain

$$\Delta q_n^* = q_n^{B*} - q_n^{G*} = \frac{N(M-N)\delta p_e}{2[2k\beta(1-\beta) - (\beta M^2 + N^2 - 2\beta MN)]} > 0.$$

Thus, we have $q_n^{G*} < q_n^{B*}$.

$$\Delta q_r^* = q_r^{B'} - q_r^{G'} = \frac{[2k(1-\beta) - M(M-N)]\delta p_e}{2[2k\beta(1-\beta) - (\beta M^2 + N^2 - 2\beta MN)]}.$$

Referring to the proof process of proposition 3, we can easily obtain:

If $\beta M < N$, then $\Delta q_r^* > 0$, namely, $q_r^{B*} > q_r^{G*}$; if $\beta M > N$, then $q_r^{B*} < q_r^{G*}$ when $k_1 < k < k_3$ and $q_r^{B*} > q_r^{G*}$ when $k_1 < k_3 < k$.

$$\Delta q_m^* = \left(q_n^{B*} + q_r^{B'}\right) - \left(q_n^{G*} + q_r^{G'}\right)$$
$$= \frac{\left[2k(1-\beta) - (M-N)^2\right]\delta p_e}{2\left[2k\beta(1-\beta) - \left(\beta M^2 + N^2 - 2\beta MN\right)\right]},$$

$$2k(1-\beta) - (M-N)^2 > 0 \Rightarrow k > \frac{(M-N)^2}{2(1-\beta)} = k_4,$$

$$k_1 - k_4 = \frac{\beta M^2 + N^2 - 2\beta MN}{2\beta(1-\beta)} - \frac{(M-N)^2}{2(1-\beta)} = \frac{N^2}{2\beta} > 0.$$

Then, we have $k_1 > k_4$, namely, $k > k_4$. Thus, $\Delta q_m^* > 0$, namely, $q_n^{B*} + q_r^{B*} > q_n^{G*} + q_r^{G*}$.

Therefore, corollary 3 is proved.

Proof of Corollary 4. According to expressions of $\Delta\tau_m^*$, Δq_n^*, Δq_r^*, and Δq_m^*, we can obtain

$$\frac{\partial\Delta\tau_m^*}{\partial k} = -\frac{2\beta N(1-\beta)^2\delta p_e}{2k\beta(1-\beta) - \left(\beta M^2 + N^2 - 2\beta MN\right)} < 0,$$

$$\frac{\partial\Delta\tau_m^*}{\partial\lambda} = \frac{(1-\beta)\delta p_e\left[2k\beta(1-\beta) - \beta M^2 + N^2 + 2\beta MN - 2\beta N^2\right]}{\left[2k\beta(1-\beta) - \left(\beta M^2 + N^2 - 2\beta MN\right)\right]^2}$$
$$> \frac{(1-\beta)\delta p_e\left[\left(\beta M^2 + N^2 - 2\beta MN\right) - \beta M^2 + N^2 + 2\beta MN - 2\beta N^2\right]}{\left[2k\beta(1-\beta) - \left(\beta M^2 + N^2 - 2\beta MN\right)\right]^2}.$$
$$= \frac{2N^2(1-\beta)^2\delta p_e}{\left[2k\beta(1-\beta) - \left(\beta M^2 + N^2 - 2\beta MN\right)\right]^2} > 0$$

Thus, we have $\frac{\partial\Delta\tau_m^*}{\partial k} < 0$ and $\frac{\partial\Delta\tau_m^*}{\partial\lambda} > 0$.

$$\frac{\partial\Delta q_n^*}{\partial k} = -\frac{\beta(1-\beta)N(M-N)\delta p_e}{\left[2k\beta(1-\beta) - \left(\beta M^2 + N^2 - 2\beta MN\right)\right]^2} < 0,$$

$$\frac{\partial\Delta q_n^*}{\partial\lambda} = \frac{(M-N)\delta p_e\left[2k\beta(1-\beta) - \beta M^2 + N^2 + 2\beta MN - 2\beta N^2\right]}{2\left[2k\beta(1-\beta) - \left(\beta M^2 + N^2 - 2\beta MN\right)\right]^2}$$
$$> \frac{(M-N)\delta p_e\left[\left(\beta M^2 + N^2 - 2\beta MN\right) - \beta M^2 + N^2 + 2\beta MN - 2\beta N^2\right]}{2\left[2k\beta(1-\beta) - \left(\beta M^2 + N^2 - 2\beta MN\right)\right]^2}.$$
$$= \frac{(M-N)N^2\delta p_e(1-\beta)}{\left[2k\beta(1-\beta) - \left(\beta M^2 + N^2 - 2\beta MN\right)\right]^2} > 0$$

Thus, we have $\frac{\partial\Delta q_n^*}{\partial k} < 0$ and $\frac{\partial\Delta q_n^*}{\partial\lambda} > 0$.

$$\frac{\partial\Delta q_r^*}{\partial k} = \frac{(1-\beta)N(\beta M - N)\delta p_e}{\left[2k\beta(1-\beta) - \left(\beta M^2 + N^2 - 2\beta MN\right)\right]^2}.$$

Thus, if $\beta M < N$, $\frac{\partial\Delta q_r^*}{\partial k} < 0$, otherwise $\frac{\partial\Delta q_r^*}{\partial k} > 0$.

$$\frac{\partial\Delta q_r^*}{\partial\lambda} = \frac{\delta p_e\left[2k(1-\beta)(2N - \beta M - \beta N) + (M-N)\left(\beta M^2 + N^2 - 2MN\right)\right]}{2\left[2k\beta(1-\beta) - \left(\beta M^2 + N^2 - 2\beta MN\right)\right]^2}.$$

Thus, if $2N - \beta M - \beta N > 0$, then $\frac{\partial\Delta q_r^*}{\partial\lambda} > 0$ when k satisfies $k > \frac{(M-N)(2MN - \beta M^2 - N^2)}{2(1-\beta)(2N - \beta M - \beta N)}$, otherwise $\frac{\partial\Delta q_r^*}{\partial\lambda} < 0$; if $2N - \beta M - \beta N < 0$, then $\frac{\partial\Delta q_r^*}{\partial\lambda} > 0$ when k satisfies $k < \frac{(M-N)(\beta M^2 + N^2 - 2MN)}{2(1-\beta)(\beta M + \beta N - 2N)}$, otherwise $\frac{\partial\Delta q_r^*}{\partial\lambda} < 0$.

$$\frac{\partial\Delta q_m^*}{\partial k} = -\frac{N^2(1-\beta)^2\delta p_e}{\left[2k\beta(1-\beta) - \left(\beta M^2 + N^2 - 2\beta MN\right)\right]^2} < 0,$$
$$\frac{\partial\Delta q_m^*}{\partial\lambda} = \frac{N(1-\beta)}{\left[2k\beta(1-\beta) - \left(\beta M^2 + N^2 - 2\beta MN\right)\right]^2} > 0.$$

Thus, we have $\frac{\partial\Delta q_m^*}{\partial k} < 0$ and $\frac{\partial\Delta q_m^*}{\partial\lambda} > 0$.

Therefore, corollary 4 is proved.

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Green supply chain integration, supply chain agility and green innovation performance: Evidence from Chinese manufacturing enterprises

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Despite widespread attention on the significance of green supply chain integration (GSCI), there is still limited research on how GSCI can improve firms' green innovation performance. From the perspective of the natural resource-based view and dynamic capability theory, based on the theoretical logic of "resource-capability-performance", this study aims to explore the relationship between GSCI and firms' green innovation performance and its intrinsic mechanism. In order to test the research model, this study collected survey data from 405 Chinese manufacturing firms and tested them by using hierarchical regression and bootstrap analysis. The results show that all three dimensions of GSCI, namely, green internal integration, green supplier integration, and green customer integration, have positive effects on supply chain agility. In addition, supply chain agility has a significant positive impact on green product and process innovation. This study also finds that supply chain agility plays a partially mediating role between all three dimensions of GSCI and green product and process innovation; that is, GSCI can further promote firms' green innovation performance by improving supply chain agility. The results of this study not only enrich the theoretical research on the driving factors of firms' green innovation but also provide policy implications for manufacturing firms and government policy-makers regarding the implementation and promotion of green innovation practices.

KEYWORDS

green internal integration, green supplier integration, green customer integration, green innovation, supply chain agility

1 Introduction

Currently, companies in various countries face many challenges brought about by environmental changes, such as global warming, energy consumption, and natural resources exhaustion, while promoting economic growth (Khan et al., 2022e; Wangsa et al., 2022). The economic growth approach, at the expense of the environment, has become a major bottleneck limiting the survival and growth of enterprises (Bildirici and Gökmenoğlu, 2017; Khan et al., 2022d). Additionally, with increasingly stringent government environmental regulations and rising awareness of environmental protection among consumers, providing green products and services in an environmentally friendly manner has become an important way for companies to gain competitive advantage (Khan et al., 2021b; Khan et al., 2022c). Therefore, seeking a sustainable development path has become a top priority. Green innovation, as the extension and promotion of traditional innovation, is regarded as a key force to balance the contradiction between economic growth and ecological environment development, and, eventually, to achieve sustainable development (Long et al., 2017). Therefore, exploring the path to improving corporate green innovation performance has become an important issue that needs to be addressed urgently.

According to the natural resource-based view (NRBV), the heterogeneous resources and unique capabilities accumulated by enterprises to respond to natural environmental challenges have a significant impact on green innovation (Hart, 1995). Due to increasing global competition and technological complexity, market competition has shifted from individual firms to supply chains (Yeh et al., 2020). It is difficult for firms to respond to the turbulent external environment by relying only on their resources, which leads to a series of challenges and risks for implementing firms' green innovation strategies (Huang and Li, 2017). Therefore, breaking through organizational boundaries and actively seeking cooperation with supply chain partners to access complementary resources has become a major means to improve firms' green innovation performance (Birasnav and Bienstock, 2019). In this context, there is a practical necessity and urgency to construct a green supply chain and implement green supply chain integration (GSCI) (Khan et al., 2021a; Mondal and Giri, 2022). GSCI refers to the extent to which companies and supply chain partners can improve resource utilization and achieve environmental goals through environmental cooperation and collaborative management of intra- and inter-organizational processes (Du et al., 2018). As an important strategy for enterprises, GSCI not only helps to enhance trust among supply chain members and promote the interaction and flow of information and knowledge resources but also helps to integrate multiple and scattered advantageous resources in the supply chain, thus compensating for the lack of corporate resources (Yang et al., 2020). Therefore, the implementation of GSCI will have an important impact on corporate green innovation performance. However, reviewing the existing literature, although the research around the theme of GSCI has attracted the attention of academic circles in recent years, scholars mainly focus on the impact of GSCI on firms' financial performance (Zhang et al., 2020) or environmental performance (Ji et al., 2020), while the impact of GSCI on green innovation performance has not received enough attention. Therefore, this study attempts to explore the relationship between GSCI and corporate green innovation performance.

In addition, although GSCI provides enterprises with access to resources (Yang et al., 2020), it is still unclear how enterprises can use acquired resources to guide their green innovation practice in a competitive and dynamic market environment (Lyu et al., 2021; Khan et al., 2022b). Therefore, to fully understand the relationship between GSCI and firms' green innovation performance, the "black box" between their relationships should be opened. In recent years, scholars have introduced dynamic capabilities from the perspective of the resource internalization process to explore the specific process by which resources act on firm performance (Parente et al., 2022). As a higher-order dynamic capability, supply chain agility helps companies quickly capture potential opportunities and risks in market competition and respond to turbulent environmental changes efficiently by rapidly arranging or coordinating organizational resources (Dubey et al., 2018), thus avoiding the negative impact of supply chain disruptions (Khan et al., 2022a; Khan and Ponce, 2022). Therefore, supply chain agility is helpful to dynamically match a company's resources with their environment to maximize their effectiveness, thus becoming an important guarantee for the effectiveness of GSCI (Shukor et al., 2021). Accordingly, this study intends to explore the role of supply chain agility in the relationship between GSCI and corporate green innovation performance from the perspective of dynamic capability to clarify the internal mechanism of the transformation from GSCI to corporate green innovation performance.

In summary, from the perspective of NRBV and DCT, based on the theoretical logic of "resource-capability-performance," this study aims to deeply explore the relationship between GSCI and corporate green innovation performance and its intrinsic mechanism by using the survey data of 405 Chinese manufacturing enterprises. In order to achieve this goal, this study tries to answer the following questions: 1) What impact of GSCI's three dimensions on supply chain agility? 2) What impact does supply chain agility have on corporate green product and process innovation? 3) Does supply chain agility mediate the relationship between GSCI's three dimensions and firms' green product and process innovation? Accordingly, this paper may have the following contributions. Firstly, this study discusses the influence of GSCI on supply chain agility and corporate green innovation performance, thus enriching the theoretical research related to GSCI. Although the importance of GSCI has gradually gained the attention of scholars in recent years, tests on its effects are still limited. Most scholars focus on discussing the impact of GSCI on corporate financial performance (Zhang et al., 2020) or environmental performance (Ji et al., 2020), but pay less attention to its impact on green innovation performance, resulting in a lack of related research. Therefore, this study explores the impact of GSCI on supply chain agility and corporate green innovation performance through empirical research, thereby expanding its scope of application. Secondly, this study discusses the influencing factors of green innovation performance from the perspective of resources and capabilities, thus enriching the antecedent research on green innovation performance. Existing research mainly focused on the influence of external factors on green innovation performance, such as stakeholder pressure (Nguyen and Adomako, 2022) and institutional factors (Zhang et al., 2022), but lacked a discussion on the antecedents of green innovation performance in the context of the supply chain. This study innovatively takes the perspective of GSCI and supply chain agility to explore their impact on green innovation performance, thereby enriching the empirical research on the influencing factors of green innovation performance under the background of "double carbon", and also opening up new ideas for the existing literature. Thirdly, this paper discusses the mediating effect of supply chain agility on the relationship between GSCI and corporate green innovation performance, thus unveiling the "black box" of the relationship between GSCI and green innovation performance. Existing research lacks the exploration of the intrinsic mechanism between GSCI and corporate green innovation performance and thus fails to clearly understand the specific process by which GSCI affects green innovation performance. Based on the theoretical logic of "resource-capability-performance", this study examines the mediating role of supply chain agility between GSCI and green innovation performance from the perspective of dynamic capability, thus clarifying the potential mechanism of GSCI affecting green innovation performance and providing a theoretical reference and practical guidance for the management practice of manufacturing enterprises using GSCI to improve their green innovation performance.

2 Literature review and hypothesis development

2.1 Green supply chain integration

Supply chain integration refers to a manufacturing firm's strategic collaboration with supply chain partners and coordinated management of intra- and inter-organizational processes to provide maximum value to customers (Flynn et al., 2010; Donkor et al., 2021). As public awareness of the environment grows, GSCI is proposed, based on traditional supply chain integration, and is defined as the extent to which manufacturing companies and their supply chain partners can improve resource utilization and achieve environmental goals through environmental cooperation and the collaborative management of intra- and inter-organizational processes (Du et al., 2018). Like supply chain integration, GSCI can be divided into three dimensions: green internal integration, green supplier integration, and green customer integration (Lo et al., 2018). Green internal integration means that companies remove cross-functional barriers and enable different departments to collaborate environmentally in strategy, decision-making, and operations to respond promptly to potential environmental issues (Shah and Soomro, 2021). Green supplier and customer integration, often referred to as external green integration, reflect the degree of cooperation between companies and their supply chain partners in environmental protection (Guo et al., 2022). Green supplier integration helps companies and suppliers understand each other's environmental responsibilities and helps companies reduce pollutant emissions at the source by jointly setting environmental goals and sharing environmental plans (Ji et al., 2020). Green customer integration helps companies better understand the green needs of the market, enabling them to achieve the same environmental goals, for both supply and demand, through joint planning (Zhao et al., 2020). Owing to the importance of GSCI, it has become a hot topic in management research in recent years, and progress has been made in related research. Some scholars have explored the antecedents of GSCI from organizational internal and external perspectives. For example, Wang and Feng (2022) argued that ethical leadership helps to improve corporate image, which in turn contributes to the implementation of GSCI. Shafique et al. (2018) found that IoT capabilities can help companies quickly collect and process data information, thus ensuring efficient green collaboration among supply chain partners and then improving GSCI. Yang et al. (2021) indicated that suitable governance mechanisms not only clarify the responsibilities and obligations between partners but also increase the commitment and trust between them, thus reducing opportunistic behavior and contributing to the efficiency of green customer integration. In addition, some scholars have provided empirical evidence for the effects of GSCI through their studies. Most of them believe that there is a "bright side" to GSCI. For example, Kong et al. (2021) found that GSCI can help to promote organizational internal and external communication and cooperation, which improves firms' financial performance. Ji et al. (2020) argued that green supplier integration helps firms to acquire advanced green technologies from their suppliers, which contributes to developing the ability of firms to cope with the environment and achieving the improvement of environmental performance. However, some scholars have confirmed that there is a "dark side" to GSCI. For example, Shi et al. (2022) found that green customer integration is usually regarded as a firm-customer-specific investment, which leads to high switching costs and increases the opportunistic behavior of partners; therefore, green customer integration may bring business risks to firms. Existing research has explored the antecedents and consequences of GSCI based on different perspectives, making an important contribution to the development of the field of GSCI and laying the foundation for subsequent research.

2.2 Green innovation performance

In recent years, with increasing environmental pollution, external pressure has forced companies to gradually improve their environmental awareness and produce green products to reduce the damage to the environment (Arroyave et al., 2020; Khan et al., 2021b); thus, green innovation was born. Green innovation, also known as environmental innovation, is defined as an innovative activity wherein companies adopt new or improved products, processes, and organizational management to reduce pollution emissions and realize the harmonious coexistence between man and nature. According to existing research, green innovation performance is usually classified into green product innovation and green process innovation (Wei et al., 2020). Green product innovation emphasizes the integration of environmental protection concepts in its life cycle to minimize the negative impact of new products on the environment (Wei et al., 2020). Green process innovation aims to reduce pollutant emissions and improve energy efficiency by improving or developing new processes (Xie et al., 2019). Unlike traditional innovation, green innovation emphasizes economic as well as environmental benefits; thus, it is considered an important way to achieve sustainable development (Long et al., 2017).

Despite a large number of studies confirming its important role, enterprises usually lack the willingness and motivation to undertake green innovation due to its double externality, characteristics of high investment and risk, and long cycle time (Bai et al., 2019). Therefore, how to efficiently promote corporate green innovation performance has become a key issue and has attracted widespread academic attention. In the existing literature, most scholars focus on the driving effects of organizational external factors on green innovation performance. For example, Zhang et al. (2022) argued that environmental regulations could stimulate firms' green innovation activities and promote continuous improvement of products and processes, thus producing an innovation compensation effect. Long and Liao (2021) pointed out that since green innovation requires a large amount of R&D investment, fiscal policy incentives can effectively compensate for the limitation of insufficient corporate funds, thus increasing firms' willingness to green innovation. Nguyen and Adomako (2022) found that the pressure from stakeholders can encourage firms to be proactive towards environmental responsibility, thus effectively promoting the implementation of corporate green innovation strategy. In addition, some scholars have shifted their research perspectives to organizational internal. For example, Zhao et al. (2021) found that executives with academic experience usually have a higher sense of social responsibility; therefore, they can better understand and take responsibility for environmental protection, which helps to improve firms' green innovation performance. Asiaei et al. (2022) confirmed that organizational intellectual capital is the intangible asset of firms, and thus it becomes a powerful driving force for firms' green innovation. Wang (2019) argued that organizational green culture helps to enhance employees' green organizational identity and enables them to better understand the company's green practices, thus promoting corporate green innovation activities. Although scholars have done a lot of research on the driving factors of green innovation performance and achieved fruitful results, the research on the impact of GSCI on green innovation performance has not received sufficient attention. In recent years, due to increasing market competition and technological changes, the development of green innovation places higher requirements on firms' knowledge structure and resource reserves, making it difficult for many enterprises to carry out green innovation independently because of talent, capital, and technology constraints (Huang and Li, 2017). In this context, GSCI, as an important strategy for enterprises, not only helps to reduce the risk of uncertainty in the process of green innovation but also integrates the multiple and scattered advantageous resources in the supply chain; this helps to realize resource sharing, complementation, and integration, and then compensates for the lack of corporate innovation resources (Yang et al., 2020; Kong et al., 2021). Therefore, it will be very effective in improving firms' green innovation performance. Based on this, this study explores the impact of GSCI's three dimensions on corporate green product and process innovation and its intrinsic mechanism, which is of strategic importance for effectively promoting and improving corporate green innovation performance.

2.3 Green supply chain integration and supply chain agility

The highly dynamic and competitive external environment has caused unprecedented pressure and challenges for companies; to survive and grow in fierce competition, the ability of companies to respond and adapt to changes quickly is particularly important (Yuan and Cao, 2022). As a higher-order dynamic capability, supply chain agility refers to a firm's ability to quickly respond to changes in a volatile environment by rapidly organizing and realigning operations and strategies within the supply chain (Dubey et al., 2018). Supply chain agility helps companies quickly capture threats and opportunities in the market environment; therefore, they can prepare with the resources to respond to the development of new services (Cai et al., 2019). Consequently, an increasing number of companies are realizing the importance of supply chain agility. Existing research suggests that the dynamic capability of an enterprise is developed through a process of combining, renewing, and developing its unique resources (Abrudan et al., 2022). Therefore, firms must have sufficient resources to improve their dynamic capabilities (Kale et al., 2019). GSCI, as an important strategy for firms, helps integrate multiple and scattered resources in the supply chain (Yang et al., 2020). Therefore, in this study, we suggest that GSCI will have a significant influence on supply chain agility.

In many companies, information and communication are usually confined within departments, causing problems of untimely information transfer, and inaccurate communication and understanding between members of different departments, which affect the firm's agile response to unforeseen situations (Roscoe et al., 2020). Green internal integration breaks down departmental barriers within the organization, enhances communication and cooperation between different departments, and enables different departments to participate in and execute the operation plan of the enterprise as early as possible (Flynn et al., 2010; Shah and Soomro, 2021), which helps each department understand and grasp the firm's resources and capabilities, and optimize the firm's resources by cooperating. Therefore, it will help firms plan effectively to respond to dynamic market changes (Khanuja and Jain, 2021). At the same time, the collaborative atmosphere created by green internal integration enhances the emotional attachment and organizational commitment of employees (Shah and Soomro, 2021). This sense of identity, in turn, improves communication efficiency among cross-functional members, facilitating better and faster decision-making by sharing information about corporate production operations in real-time, thus speeding up problem-solving (Liu et al., 2018; Ramos et al., 2021). In addition, the breadth and richness of knowledge acquired by an enterprise is an important prerequisite for enhancing agility, that is, the richer the knowledge base of an enterprise, the stronger its ability to cope with and resolve uncertainties in the market environment (Ji et al., 2020; Parente et al., 2022). Green internal integration enhances the mutual understanding and common expectations of corporate environmental strategies within the enterprise, thus greatly reducing friction and hindrance in communication and cooperation, which helps to facilitate the flow of explicit and implicit knowledge among members within the enterprise. Moreover, in the process of continuous capital accumulation, the collision of different modes of thinking helps break the confinement of the inherent knowledge structure to employees, and realize the reorganization and creation of knowledge (Kong et al., 2020; Roscoe et al., 2020). New knowledge can effectively stimulate the potential of knowledge within the organization (Luo et al., 2018), which helps enterprises predict the trend of environmental changes more accurately and revisit the opportunities and challenges in the external environment, thus enhancing their ability to respond to changes and providing the possibility of improving supply chain agility (Cheng and Lu, 2017). Thus, we propose the following hypothesis:

H1: Green internal integration has a positive impact on supply chain agility.

Green external integration creates an atmosphere of mutual trust between enterprises, which allows them to share risks and benefits with supply chain partners, thus building a long-term and stable cooperation network between them (Guo et al., 2022). This stable partnership helps enhance mutual trust and dependence, thus reducing the risk of resource spillover and speculation in cooperation and mitigating the tendency of opportunistic behavior by supply chain members. This facilitates the interaction and flow of information and knowledge within the supply chain (Zhao et al., 2021), and further improves supply chain agility. Specifically, green supplier and customer integration improve the communication efficiency among supply chain members, facilitating high-quality information-sharing in all aspects of production planning, inventory levels, and demand forecasting, thus helping companies to develop more robust response strategies (Wong et al., 2020; Kong et al., 2021). For example, green supplier integration allows companies and suppliers to have a deeper understanding of each other's business and mutual needs, which facilitates suppliers to adjust their supply plans promptly, thus improving the company's ability to respond to supply market dynamics (Ji et al., 2020). Green customer integration helps in the timely acquisition of valuable market information, such as environmental demands, environmental policies, and competitor development, which helps companies grasp the overall market trends and take prompt actions to respond to dynamic changes in the environment, thus improving supply chain agility (Mao et al., 2017; Ramos et al., 2021).

Suppliers and customers are important sources of green knowledge for companies (Melander, 2018). Green external integration strengthens the continuous interaction between enterprises, suppliers, and customers, forming an embedded relationship network. This not only enriches the channels for enterprises to acquire knowledge, but also facilitates enterprises to carry out learning activities across organizational boundaries, thus expanding the scope of knowledge search and promoting enterprises to acquire diversified knowledge resources (Du et al., 2018; Yeh et al., 2020). Moreover, compared to general knowledge sources, the external knowledge acquired through green suppliers and customers has higher harmony and validity, which will help improve the efficiency of enterprises' adoption of external knowledge (Wei et al., 2020). The organic integration of internal and external knowledge helps improve the thinking of enterprises, encouraging them to think beyond convention, thus providing more feasible solutions and countermeasures for enterprises, reducing the response time to environmental changes, and improving supply chain agility (Martínez-Ros and Kunapatarawong, 2019; Donbesuur et al., 2021). Thus, we propose the following hypotheses:

H2: Green supplier integration has a positive impact on supply chain agility.

H3: Green customer integration has a positive impact on supply chain agility.

2.4 Supply chain agility and corporate green innovation performance

According to the DCT, the ability of an enterprise to adjust organizational resources to adapt to changes in external environment will help the firm survive and thrive in a turbulent environment, thereby improving its green innovation performance (Teece, 2007). As an important part of dynamic capabilities, supply chain agility helps companies reconfigure and update their organizational resources to respond quickly to external environmental change (Dubey et al., 2018), which makes it a prerequisite for green innovation (Zhu and Gao, 2021).

Supply chain agility increases the flexibility of companies, making them sensitive to the dynamic changes of external environment (Cai et al., 2019) and also keep abreast of the government's environmental policy requirements and competitors' developments, which helps them fully grasp the green demand in the market and their own development direction (Zhou et al., 2018). This reduces the risk and uncertainty of exploring green innovation, thus improving corporate green innovation performance (Singh et al., 2022). In addition, supply chain agility helps companies identify potential market opportunities accurately, thereby gaining the time to innovate (Shahzad et al., 2020). When a company with higher agility identifies potential green opportunities in the market, it can quickly optimize its resources and fully mobilize them to invest heavily in green products or processes that are more compatible with the market (Yuan and Cao, 2022). This not only shortens the company's response time to new demands and increases the speed of new product development significantly (Hoonsopo and Puriwat, 2021), but also prepares resources for enterprises to implement green innovation strategy (Cai et al., 2019), thus promoting green product and process innovation. Simultaneously, good market performance increases stakeholders' confidence in the company, which in turn attracts more external resources to further support the firm's green innovation activities (Pan et al., 2021). In addition, supply chain agility alerts companies to potential risks of environmental changes, thereby increasing their sensitivity and risk resistance to the external environment (Riquelme-Medina et al., 2022). Agile enterprises can promptly handle unexpected crises, finding specific countermeasures to resolve problems, and actively adjusting the factors unfavorable to their development, thus reducing or avoiding the negative effects of supply chain disruption risks (Abdelilah et al., 2021; Khan et al., 2022a; Riquelme-Medina et al., 2022), this guarantees the smooth implementation of green innovation activities, and creates excellent green innovation performance. Thus, we propose the following hypotheses:

H4: Supply chain agility has a positive impact on green product innovation.

H5: Supply chain agility has a positive impact on green process innovation.

2.5 Mediating role of supply chain agility

Owing to the high risk and uncertainty of green innovation, it is difficult for firms to implement green innovation with their resources; thus, they need to cooperate with supply chain partners to obtain the required resources (Ocicka et al., 2022). Existing research suggests that firms' innovation resources may come from both inside and outside the organization (Kafouros et al., 2020). GSCI helps integrate multiple and scattered advantageous resources in the supply chain, thus providing access to resources for enterprises (Yang et al., 2020). However, it is difficult for firms to guarantee the smooth implementation of green innovation by only having abundant static resources, and enterprises need to have a certain dynamic ability to quickly adjust internal and external resources to dynamically match their environment and effectively improve green innovation (Du et al., 2018; Shukor et al., 2021). Therefore, this study argues that GSCI will impact corporate green innovation performance by improving supply chain agility. Specifically, GSCI builds a collaborative atmosphere of mutual sharing and joint participation, which enables the establishment of deep cooperation among different departments, suppliers, and customers, and effectively improves the level of information sharing among them (Kong et al., 2021). This close and continuous information sharing helps enterprises obtain high-quality green information and critical complementary environmental knowledge resources (Kong et al., 2020), thus improving supply chain agility. Higher agility helps enterprises quickly identify green opportunities in the market and develop response plans before competitors, thus preparing resources and activities for green innovation activities (Cai et al., 2019; Yuan and Cao, 2022). At the same time, this agility helps to improve corporate environmental perception, keeping them constantly alert to potential risks in unpredictable environments. This reduces the risk of supply chain disruptions (Abdelilah et al.,

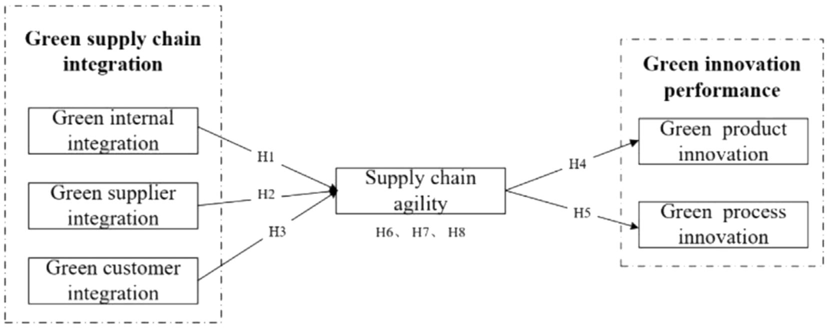

FIGURE 1
Conceptual model.

2021; Khan et al., 2022a; Riquelme-Medina et al., 2022) and guarantees the stable operation of the supply chain system, which ultimately improves corporate green innovation performance. Thus, we propose the following hypotheses:

H6: Supply chain agility positively moderates the relationship between green internal integration and (a) green product innovation and (b) green process innovation.

H7: Supply chain agility positively moderates the relationship between green supplier integration and (a) green product innovation, and (b) green process innovation.

H8: Supply chain agility positively moderates the relationship between green customer integration and (a) green product innovation, and (b) green process innovation.

Based on the above analysis, a conceptual model is proposed for this study, as shown in Figure 1.

3 Research methodology

3.1 Sampling and data collection

Manufacturing is an important driving force for China's boom economy and a major source of industrial pollution emissions. Chinese companies are facing increasingly stringent environmental regulations in the context of the "double carbon" target. Consequently, Chinese companies are placing great emphasis on investing in green innovation (Zhang et al., 2022). Moreover, firms in China are highly dependent on the network of relationships among supply chain members (Yanga and Linb, 2020); therefore, this provides an ideal research background for this study to explore the interactions between the variables. Based on this, this study collected relevant data from Chinese manufacturing firms by using a questionnaire survey. In this study, the measurement scales were derived from well-established scales in the existing literature. To ensure the accuracy of the data, we first followed the methods of translation and back translation to ensure accurate language expression and easy understanding of the semantic meaning. Second, we invited four experts with relevant research experience to evaluate the initial scale and selected senior managers for long-term cooperation with the subject group, for preliminary testing of the questionnaire before the formal research of the questionnaire, thereby modifying and improving it according to the pre-research and experts' feedback to form the final measurement scale. From April 2022 to July 2022, we distributed 860 questionnaires through the research team's network with the senior management of relevant enterprises and professional third-party research platforms. After excluding invalid questionnaires, 405 were obtained, with a usable response rate of 47.09%. The detailed distribution of sample characteristics is presented in Table 1.

3.2 Measures

In this study, the variables were measured on a seven-point Likert scale, with 1–7 indicating the degree of agreement with the description of the question. Among them, 1 means, "very non-conforming" and 7 means, "very conforming". (See Supplementary Appendix SA1).

3.2.1 Green innovation performance

Green innovation performance is an important indicator that can reflect the implementation of corporate green innovation strategy. Drawing on Wei et al. (2020), this study uses green product and process innovation to measure green innovation performance. The indicators of each dimension were measured with five items.

TABLE 1 Profile of sampled firms.

Characteristics of firms	Number	Percentage (%)
Firm age		
≤5	22	5.4
6–10	82	20.2
11–15	128	31.6
≥16	173	42.7
Ownership		
State-owned	96	23.7
Privately owned	274	67.7
Joint venture	26	6.4
Foreign owned	9	2.2
Number of employees		
≤100	42	10.4
101–300	101	24.9
301–500	77	19
501–1,000	80	19.8
1,001–2000	42	10.4
>2000	63	15.6
Industry		
Food products	57	14.1
Communication and computers related equipment	65	16
Pharmaceutical and medical	38	9.4
General equipment	69	17
Electrical machinery and equipment	60	14.8
Chemical products and petrochemical industry	13	3.2
Automobile and transport equipment	46	11.4
Textiles and apparel	22	5.4
Others	35	8.6
Total	405	

3.2.2 Green supply chain integration

Drawing on Kong et al. (2021), this study measures GSCI from three dimensions: green internal integration, green supplier integration, and green customer integration. The indicators of each dimension were measured with five items.

3.2.3 Supply chain agility

Supply chain agility usually reflects the ability of firms in the supply chain to perceive and respond to changes in the market environment (Zhu and Gao, 2021). Therefore, drawing on Altay et al. (2018) and Aslam et al. (2020), this study considers these two abilities as evaluation criteria for supply chain agility and uses six items to measure them.

3.2.4 Control variables

Based on previous studies (Ji et al., 2020), firm age, ownership, size, and industry type were selected as control variables to control for potential confounding impacts. Firm age and size were measured by the number of operational years and number of employees, respectively. Firm ownership was measured using a dummy variable with 1 = state-owned enterprise and 0 = otherwise. Firm industry type was measured using a dummy variable with 1 = highly polluting industry and 0 = otherwise.

3.3 Reliability and validity

To ensure the reliability and validity of the subsequent empirical analysis, this paper uses SPSS and AMOS software to test the reliability and validity of all variables, and Table 2 shows the test results. In terms of reliability, the Cronbach's α value of each measurement variable was greater than 0.70, and the composite reliability (CR) value of each measurement variable was above 0.70, indicating that the measurements in this study have good reliability. Validity includes both content and structural validity. In terms of content validity, the scales of

TABLE 2 Measurement reliability and validity.

Variables	Items	Factor loadings	Cronbach's α	CR	AVE
Green internal integration (GII)	GII1	0.773	0.885	0.886	0.608
	GII2	0.743			
	GII3	0.777			
	GII4	0.801			
	GII5	0.804			
Green supplier integration (GSI)	GSI1	0.795	0.884	0.885	0.606
	GSI2	0.740			
	GSI3	0.744			
	GSI4	0.782			
	GSI5	0.828			
Green customer integration (GCI)	GCI1	0.813	0.881	0.882	0.600
	GCI2	0.757			
	GCI3	0.771			
	GCI4	0.758			
	GCI5	0.770			
Supply chain agility (SCA)	SCA1	0.749	0.895	0.897	0.593
	SCA2	0.755			
	SCA3	0.775			
	SCA4	0.762			
	SCA5	0.784			
	SCA6	0.794			
Green product innovation (GPDI)	CP1	0.774	0.854	0.857	0.600
	CP2	0.775			
	CP3	0.766			
	CP4	0.782			
Green process innovation (GPCI)	LC1	0.853	0.913	0.914	0.726
	LC2	0.861			
	LC3	0.860			
	LC4	0.834			

Note: Model fit statistics: χ^2/df = 1.050; RMSEA = 0.011; GFI=0.940; NFI=0.945; IFI = 0.997.

this study were all from the well-established scales in the existing literature and were modified after discussion and pre-testing by relevant experts and scholars, which ensured the content validity of the scales to a certain extent. Structural validity usually includes convergent and discriminant validity. As shown in Table 2, the standardized factor loading values of each measurement variable are greater than 0.70, and the average variance extracted (AVE) values of each measurement variable are greater than 0.50, indicating that the scale used in this study has good convergent validity. The square root of the AVE in Table 3 is higher than the correlation coefficient between the factors, indicating that the scale has good discriminant validity. In addition, the results of the validation factor analysis showed that the indices χ^2/df (<3.000), RMSEA (<0.080), GFI, NFI, and IFI (>0.900) were within a good range, indicating a good fit of the model. In conclusion, the measurements in this study have good reliability and validity.

3.4 Common method variance

Although the questionnaire was reasonably designed and refined before the survey data, and it was emphasized that the collected data were used only for academic research, as much as possible, the problem of common method variance may still arise because all the questions in the questionnaire were filled in by the same respondents. Therefore, this paper use Harman's single-factor test to test the common method variance. The results showed that the first factor explained 29.393% of the total variance, which was less than 40%, indicating that there was no serious common method variance.

TABLE 3 Summary and correlation of variables.

Variables	Mean	S.D.	Age	Ownership	Size	Industry	GII	GSI	GCI	SCA	GPDI	GPCI
Age	3.116	0.914	1									
Ownership	0.237	0.426	0.126*	1								
Size	3.415	1.585	0.445**	0.265**	1							
Industry	0.331	0.471	0.054	−0.022	−0.038	1						
GII	4.254	1.149	Measurement reliability and −0.066	−0.094	−0.028	−0.020	**0.780**					
GSI	4.072	1.175	0.045	−0.019	0.091	−0.010	0.114*	**0.778**				
GCI	4.410	1.102	0.000	0.053	0.019	−0.054	0.120*	0.136**	**0.774**			
SCA	4.011	0.910	0.082	0.012	0.045	−0.082	0.299**	0.382**	0.357**	**0.770**		
GPDI	4.219	0.983	−0.096	0.000	-0.042	0.009	0.280**	0.322**	0.274**	0.401**	**0.774**	
GPCI	4.249	1.154	0.030	−0.052	−0.023	−0.111*	0.272**	0.343**	0.277**	0.444**	0.372**	**0.852**

Note: The number in bold in the diagonal of the correlation matrix is the square root of the AVEs. *p < 0.05; **p < 0.01.

4 Analyses results

In this study, SPSS software was used to test the research hypotheses using hierarchical regression analysis. Before testing the research hypotheses, this study examined multicollinearity among the variables. As shown in Table 3, the means and standard deviations of the variables were within a reasonable range, and there was a correlation between the main variables. In addition, the correlation coefficients between the variables were all less than 0.7, and the variance inflation factor (VIF) values of each variable were all less than 2. This indicates that multicollinearity is not an issue, which meets the requirements for further regression analysis. The regression results are presented in Table 4 and Figure 2.

In Table 4, Model 1 is a regression model of control variables on supply chain agility, and Model 2 adds three dimensions of GSCI based on Model 1. The results show that green internal integration ($\beta = 0.236$, $p < 0.001$), green supplier integration ($\beta = 0.316$, $p < 0.001$), and green customer integration ($\beta = 0.282$, $p < 0.001$) have significant positive effects on supply chain agility. Meanwhile, compared to Model 1, the R^2 of Model 2 improved by 0.290 after including GSCI, and the F-test also reveals that ΔR^2 is significant. Hence, Hypotheses H1, H2, and H3 are supported.

Models 5 and 9 were used to test the impact of supply chain agility on green product and process innovation. Model 3 is the regression model of the control variables for green product innovation. Model 5 adds supply chain agility based on Model 3, and the results show that supply chain agility has a significant positive impact on green product innovation ($\beta = 0.416$, $p < 0.001$). Meanwhile, compared to Model 3, the R^2 of Model 5 improved by 0.170 after including supply chain agility, and the F-test also reveals that ΔR^2 is significant. Hence, H4 is supported. Model 7 is a regression model of the control variables on green process innovation, and Model 9 adds

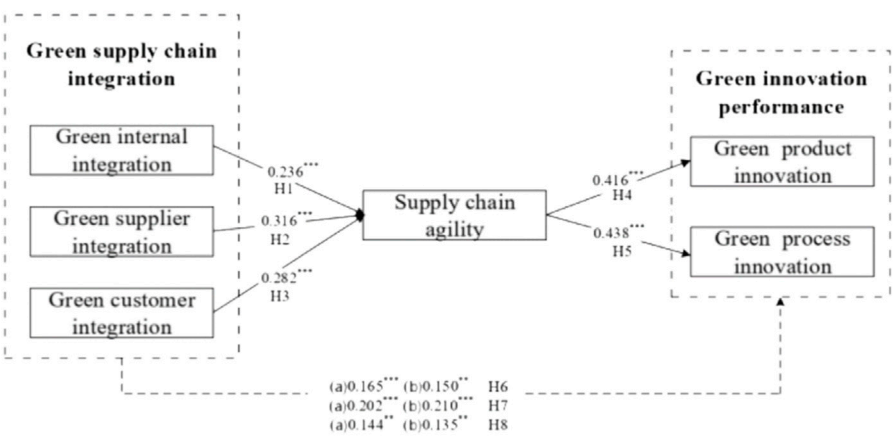

FIGURE 2
Regression model coefficients.

TABLE 4 Results of regression analysis.

Variables	SCA		GPDI				GPCI			
	Model1	Model2	Model3	Model4	Model5	Model6	Model7	Model8	Model9	Model10
Control variables										
Age	0.086	0.101*	−0.098†	−0.084†	−0.133**	−0.108*	0.061	0.074	0.024	0.048
Ownership	−0.001	0.021	0.013	0.036	0.014	0.031	−0.052	−0.029	−0.051	−0.034
Size	0.004	−0.036	−0.001	−0.036	−0.002	−0.027	−0.041	−0.077	−0.043	−0.068
Industry	−0.086	−0.065	0.015	0.032	0.051	0.047	−0.117*	−0.100*	−0.079†	−0.083
Independent variables										
GII		0.236***		0.221***		0.165***		0.212***		0.150**
GSI		0.316***		0.276***		0.202***		0.293***		0.210***
GCI		0.282***		0.211***		0.144**		0.210***		0.135**
Mediator										
SCA					0.416***	0.236***			0.438***	0.264***
R^2	0.014	0.304	0.010	0.219	0.180	0.257	0.018	0.233	0.208	0.281
F	1.445	24.790***	0.964	15.861***	17.510***	17.154***	1.878	17.238***	20.944***	19.392***
ΔR^2	0.014	0.290	0.010	0.209	0.170	0.039	0.018	0.215	0.189	0.048
ΔF	1.445	55.135***	0.964	35.392***	82.902***	20.696***	1.878	37.041***	95.433***	26.670***

Note: †$p < 0.1$; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

supply chain agility based on Model 7. The results show that supply chain agility has a significant positive effect on green process innovation ($\beta = 0.438$, $p < 0.001$). Meanwhile, compared to Model 7, the R^2 of Model 9 improved by 0.189 after including supply chain agility, and the F-test also reveals that ΔR^2 is significant. Hence, H5 is supported.

This study constructs model 4 and model 6 and uses the stepwise regression method to validate the mediating effect of supply chain agility on the relationship between the three dimensions of GSCI and green product innovation. In Table 4, Model 4 shows that green internal integration ($\beta = 0.221$, $p < 0.001$), green supplier integration ($\beta = 0.276$, $p < 0.001$), and green customer integration ($\beta = 0.211$, $p < 0.001$) have significant positive effects on green product innovation. Model 6 adds supply chain agility based on Model 4, and the results show that the positive effects of green internal integration ($\beta = 0.165$, $p < 0.001$), green supplier integration ($\beta = 0.202$, $p <$ 0 0.001) and green customer integration ($\beta = 0.144$, $p < 0.01$) on green product innovation become smaller, but are still significant, after including supply chain agility. Meanwhile, compared to Model 4, the R^2 of Model 6 improved by 0.039 after including supply chain agility, and the F-test also reveals that ΔR^2 is significant. Hence, supply chain agility partially mediates the relationship between all three dimensions of GSCI and green product innovation. In addition, Models 8 and 10 were constructed in this study to test the mediating effect of supply chain agility on the relationship between the three dimensions of GSCI and green process innovation. Model 8 in Table 4 shows that green internal integration ($\beta = 0.212$, $p < 0.001$), green supplier integration ($\beta = 0.293$, $p < 0.001$), and green customer integration ($\beta = 0.210$, $p < 0.001$) have significant positive effects on green process innovation. Model 10 adds supply chain agility based on Model 8, and the results show that the positive effects of green internal integration ($\beta = 0.150$, $p < 0.01$), green supplier integration ($\beta = 0.210$, $p < 0.001$), and green customer integration ($\beta = 0.135$, $p < 0.01$) on green process innovation become smaller, but are still significant, after including supply chain agility. Meanwhile, compared to Model 8, the R^2 of Model 10 improved by 0.048 after including supply chain agility, and the F-test also reveals that ΔR^2 is significant. Hence, supply chain agility partially mediates the relationship between all three dimensions of GSCI and green process innovation. In summary, Hypotheses H6, H7, and H8 are supported.

In addition, this study used bootstrap analyses (repeated sampling 5,000 times) to further examine and verify the mediating effect of supply chain agility. If the 95% bias-corrected confidence intervals do not include 0, the mediating effect is significant; the test results are shown in Table 5. In Table 5, the indirect effects of green internal integration, green supplier integration, and green customer integration on green product innovation through supply chain agility are 0.096, 0.108, and 0.115, respectively. The 95% bias-corrected confidence intervals [0.057, 0.141], [0.069, 0.152], and [0.073, 0.164] do not include 0, indicating that the mediating effect of supply chain agility is significant. In addition, the indirect effects of green internal integration, green supplier integration, and green customer integration on green process innovation, through

TABLE 5 Bootstrapped mediation results.

Model	Total effect		Direct effect		Indirect effect		
	Coefficient	t value	Coefficient	t value	Point estimate	Lower	Upper
GII→SCA→GPDI	0.041***	5.784	0.040***	3.525	0.096	0.057	0.141
GSI→SCA→GPDI	0.040***	6.992	0.040***	4.167	0.108	0.069	0.152
GCI→SCA→GPDI	0.043***	5.751	0.430**	3.062	0.115	0.073	0.164
GII→SCA→GPCI	0.048***	5.654	0.047**	3.247	0.121	0.077	0.170
GSI→SCA→GPCI	0.460***	7.399	0.047***	4.419	0.134	0.087	0.188
GCI→SCA→GPCI	0.050***	5.778	0.496**	2.917	0.145	0.094	0.201

Note(s): $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$. 95% CI: Bias corrected bootstrap 95% confidence interval based on 5,000 bootstrap samples.

supply chain agility, are 0.121, 0.134, and 0.145, respectively. The 95% bias-corrected confidence intervals [0.077, 0.170], [0.087, 0.188], and [0.094, 0.201] do not include 0, indicating that the mediating effect of supply chain agility is significant. The results of this analysis further support H6, H7, and H8.

5 Discussion

Combining NRBV and DCT, based on the analytical logic of "resource-capability-performance", this study constructs a theoretical model of GSCI, supply chain agility, and corporate green innovation performance and aims to deeply explore the relationship between GSCI and corporate green innovation performance and its intrinsic mechanism. Based on this, this study uses hierarchical regression and bootstrap analysis to test the survey data of 405 Chinese manufacturing firms and draws the following conclusions.

Firstly, all three dimensions of GSCI have positive impacts on supply chain agility. Specifically, the close cooperation network built by GSCI promotes deep communication among supply chain members and helps enterprises to search and acquire a large number of valuable resources, such as information, technology, and knowledge (Yang et al., 2020), thus playing an important role in promoting supply chain agility. Among them, green internal integration enhances communication within the organization and helps enterprises achieve a centralized allocation of resources to respond to environmental changes (Flynn et al., 2010; Khanuja and Jain, 2021), thereby improving supply chain agility. Green supplier and customer integration build a cooperative atmosphere of mutual trust among supply chain members, which enhances the closeness of the mutual relationship and helps shorten the transmission time and path of complementary resources in cooperation (Du et al., 2018; Zhao et al., 2021). Consequently, it will accelerate the speed of multiple options and the response of enterprises to cope with environmental uncertainty (Martínez-Ros and Kunapatarawong, 2019; Donbesuur et al., 2021), thereby contributing to the cultivation and shaping of supply chain agility.

Secondly, supply chain agility improves firms' green innovation performance. Supply chain agility is a dynamic process whereby enterprises reconfigure and optimize their resources, which is an important prerequisite for the successful implementation of a firm's green innovation strategy (Dubey et al., 2018; Zhu and Gao, 2021). On the one hand, supply chain agility increases the flexibility and sensitivity of enterprises; therefore, they can discover potential green opportunities in the market before their competitors and fully mobilize internal and external resources of enterprises to invest in green innovation activities in line with market demand, thus gaining the time to innovate and contributing to the generation of new products and processes (Yuan and Cao, 2022). On the other hand, enterprises with higher supply chain agility can timely perceive the potential risks and threats in the environment and reduce the risk of supply chain disruption by quickly adjusting corporate strategy (Abdelilah et al., 2021; Khan et al., 2022a; Riquelme-Medina et al., 2022), which guarantees the smooth implementation of green innovation activities and thus improving green product and process innovation performance.

Thirdly, supply chain agility plays a partial mediating role in the relationship between all three dimensions of GSCI and corporate green innovation performance. This finding confirms the bridging role of supply chain agility in corporate green innovation activities; that is, the three dimensions of GSCI not only have a direct impact on corporate green innovation performance but can also indirectly promote them by improving supply chain agility. Specifically, GSCI helps form a strong relationship network among supply chain members, provides a channel for the interaction and flow of information and knowledge among enterprises (Yang et al., 2020), improves the knowledge system of enterprises, and provides more feasible options for enterprises to solve problems (Martínez-Ros and Kunapatarawong, 2019; Donbesuur et al., 2021), which, in turn, improves supply chain agility. This higher supply chain agility enables enterprises to quickly perceive potential market opportunities and risks in a turbulent environment and effectively absorb, reorganize and transform the acquired information and technical resources by flexibly allocating and integrating internal and external resources (Dubey et al., 2018), thus laying a solid foundation for improving corporate green product and process innovation.

6 Conclusion

In the context of low-carbon economy, enterprises are faced with the double challenges of economic growth and environmental protection. Green innovation, as a new form of innovation from the perspective of ecological civilization, has become an inevitable choice for enterprises to achieve sustainable development (Long et al., 2017). Therefore, how to effectively improve corporate green innovation performance has become an important issue. However, due to increasing global competition and technological complexity, market competition has shifted from individual firms to supply chains (Yeh et al., 2020). It is difficult for firms to respond to the turbulent external environment by relying only on their own resources, which leads to a series of challenges for firms to implement green innovation strategies (Huang and Li, 2017). Therefore, enterprises need to seek collaboration with supply chain partners to obtain richer innovative resources (Birasnav and Bienstock, 2019). In recent years, GSCI has become one of the main ways for enterprises to acquire resources effectively. However, the research on the relationship between GSCI and green innovation performance in the existing literature has not received sufficient attention. Therefore, combining NRBV and DCT, based on the theoretical logic of "resources-capabilities-performance", this study examines the relationship between GSCI and green innovation performance and its intrinsic mechanism. Through the empirical research on the survey data of 405 Chinese manufacturing enterprises, this study finds that all three dimensions of GSCI, namely, green internal integration, green supplier integration, and green customer integration, have positive effects on supply chain agility. Supply chain agility can significantly improve corporate green product and process innovation. In addition, supply chain agility plays a partially mediating role in the relationship between all three dimensions of GSCI and corporate green product and process innovation. In summary, this paper shows that enterprises should actively implement GSCI to improve supply chain agility, thereby improving their green innovation performance.

6.1 Theoretical contributions

The research of this study is helpful to deeply understand the relationship between GSCI and firms' green innovation performance and its intrinsic mechanism, thus making the following theoretical contribution to existing research. Firstly, this study examines the impact of GSCI on supply chain agility and corporate green innovation performance, thus enriching and expanding theoretical research in the field of GSCI. In recent years, the importance of GSCI has been gradually recognized, and related research has made some progress. However, in general, the existing studies are limited in their testing of the effect of GSCI. Most scholars focus on the impact of GSCI on corporate financial performance (Zhang et al., 2020) or environmental performance (Ji et al., 2020), while the impact of GSCI on green innovation performance has not been clearly explained and tested. Therefore, this study explores the effect of GSCI on supply chain agility and two types of green innovation performance (i.e., green product innovation and green process innovation) through empirical research, thus expanding the scope of the effect of GSCI and enriching its research framework.

Secondly, this study explores the driving factors of corporate green innovation from the perspective of resources and capabilities, which enriches the antecedents of green innovation. Green innovation is regarded as an important way for enterprises to achieve sustainable development (Long et al., 2017), and it is especially important to clarify how to improve corporate green innovation performance in the context of the "double carbon". Previous studies mainly focused on the impact of external factors on green innovation, such as stakeholder pressure (Nguyen and Adomako, 2022) and institutional factors (Zhang et al., 2022), but lacked a discussion on the antecedents of green innovation performance in the context of the supply chain. This study innovatively explores their influence on green innovation performance from the perspective of GSCI and supply chain agility, thus enriching the research on the promotion path of firms' green innovation performance in the context of "double carbon" and providing new ideas and perspectives for theoretical research in the field of green innovation.

Thirdly, this study verifies the mediating role of supply chain agility on the relationship between GSCI and firms' green innovation performance, thus revealing the pathway through which GSCI influences firms' green innovation performance. Existing research lacks a discussion of the internal mechanism between GSCI and corporate green innovation performance, which prevents a clear understanding of the specific process by which GSCI affects green innovation performance. Based on the theoretical logic of "resource-capability-performance", this study integrates GSCI, supply chain agility, and corporate green innovation performance into the same framework and explores the mediating role of supply chain agility between GSCI and green innovation performance, thus opening the "black box" of the relationship between them from the perspective of dynamic capability, providing a micro knowledge base for the theoretical study of how GSCI can transform into corporate green innovation performance. Meanwhile, it also deepens the theoretical understanding of the realization path to improve corporate green innovation performance.

6.2 Management insights

The findings of this study have important management insights for corporate green innovation practices and government policy formulation. Firstly, in the context of a low-carbon economy, GSCI provides an effective path for manufacturing enterprises to improve their green innovation performance. Therefore, enterprises need to cooperate deeply with their supply chain partners and establish a long-term relationship of information communication and resource sharing, thereby effectively improving their green innovation performance. On the one hand, enterprise managers should attach great importance to the role of GSCI, actively establish network connections with supply chain members, and integrate green concepts into every link of the supply chain, thereby continuously promoting the implementation of the GSCI strategy. Meanwhile, enterprises should enrich diversified participation channels so that they can integrate into more green supply chain network ecosystems, thus expanding the breadth and depth of GSCI and increasing the opportunities and channels to acquire diversified resources. On the other hand, enterprises should continuously improve their green supply chain management capabilities and create a good cooperation environment for supply chain members through effective communication and coordination to strengthen the cooperation among supply chain members and improve the quality of integration, thereby bringing into play the maximum effectiveness of GSCI and paving the way for their green innovation. Secondly, enterprise managers should fully recognize the important role of supply chain agility in the relationship between GSCI and green innovation performance. Therefore, in the process of GSCI, enterprises should incorporate supply chain agility into their long-term strategic planning and pay attention to the construction and improvement of supply chain agility. Specifically, enterprises should actively establish close network relationships with supply chain members to obtain more complementary resources. In addition, enterprises should further strengthen their information system construction and enhance information processing capability to guarantee the rapid and accurate flow of information within the organization to maximize supply chain agility, thereby giving full play to the role of GSCI and achieving the continuous improvement of green innovation performance. Finally, as an important regulator, the government should give full play to its guiding and coordinating role in GSCI. On the one hand, the government should strengthen contact with enterprise managers, make them establish good green values, and enhance their sense of environmental responsibility through various training methods, such as environmental education, technical exchange, and entrepreneurial forum, thereby effectively increasing the willingness of enterprises to implement GSCI. On the other hand, the government should establish a sharing platform and introduce encouraging policies to provide policy guidance and financial support for the formation of green supply chain networks and the selection of corporate partners, thus further improving the level of enterprises' implementation of GSCI, and then helping firms' green innovation practices.

6.3 Research limitations and future developments

Although some research results have been achieved in our study, there are still certain limitations which need to be improved in future research. Firstly, all data in this study were obtained through questionnaires. Although some methods were used to avoid common method variance, and the statistical test shows that they were within acceptable limits, future studies still need to further test the research through multiple sources of data to increase the robustness of the findings. Secondly, this study uses static cross-sectional data, which cannot clearly reflect the dynamic impact of GSCI on corporate green innovation performance. Future research can explore the dynamic changes in the relationship between GSCI and corporate green innovation performance through longitudinal or experimental research. Thirdly, this study focuses on the relationship and intrinsic mechanism between GSCI and corporate green innovation performance, ignoring the contextual factors that may affect this relationship. Future research can actively explore the boundary conditions of the relationship between GSCI and corporate green innovation performance, thereby further deepening the existing research. Finally, this study only investigates the data of Chinese manufacturing enterprises. Due to China's special cultural and economic backgrounds, this may lead to the fact that our findings may not be applicable to other countries. Therefore, future research can use more cross-country sample data to investigate the relationship and underlying mechanism between GSCI and corporate green innovation performance and compare whether the differences between different countries affect the relationship to obtain richer research findings.

Data availability statement

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

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the participants was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

BZ: data curation, validation, visualization, writing–review, and editing. SZ: conceptualization, supervision, and writing—original draft. XF: methodology, formal analysis. SW: Software, writing—review, and editing. DS: writing—review and editing.

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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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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2022.1045414/full#supplementary-material

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Does environmental administrative penalty promote the quantity and quality of green technology innovation in China? Analysis based on the peer effect

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As the guarantee for the effective implementation of environmental policies, the spillover of the deterrent effect of environmental administrative penalties is crucial for solving the environmental regulatory dilemma. It is also unclear whether environmental administrative penalties can affect green technology innovation of the peer enterprises and whether they have an impact on both the quantity and quality dimensions. Taking listed firms of heavily polluting industries in China's Shanghai and Shenzhen A-share from 2016 to 2020 as the sample, this paper analyzes the impact of the environmental administrative penalty on the quantity and quality of corporate green technology innovation based on the perspective of peer effect. The results indicate that: 1) Environmental administrative penalty significantly promotes the quantity and quality of peer enterprises' green technology innovation. 2) Heterogeneity analysis shows that the diversity of penalties, the competitiveness of the penalized enterprises, and the property rights of peer enterprises all contribute to the different impacts of the environmental administrative penalty on the peer enterprises' green technology innovation. 3) Further analysis shows that the promotion effect will be weakened when peer enterprises face high financing constraints. The research results expand the related research on direct government regulation and green technology innovation from the perspective of peer effect and provide policy reference for the government to formulate differentiated penalty policies according to the heterogeneity of enterprise.

KEYWORDS

environmental administrative penalty, green technology innovation, peer effect, heterogeneity, moderating effect

Abbreviations: GTI, green technology innovation.

1 Introduction

Since the 20th century, environmental pollution has become a global issue. Economic growth and urbanization have brought great challenges to resources and the environment (Ali et al., 2022). As the world's second-largest economy, China is actively exploring ways to balance economic and environmental development. The 20th National Congress of the Communist Party of China proposed to further promote the prevention and control of environmental pollution and realize the green transformation of development mode. It demonstrates China's determination and efforts in achieving a balance of economic and environmental development once again. At the congress, Chinese leaders repeatedly emphasized, "Innovation is the first driving force that leads development." Green technology innovation (GTI) takes into account the dual benefits of economic development and environmental protection (Hua and Li, 2022). In the context of enterprises being recognized as one of the main sources of environmental pollution (Shevchenko, 2020), promoting enterprises to carry out GTI is the fundamental way and important driving force for the development of a green economy (Hong et al., 2021). China has been increasing its innovation efforts in recent years. In 2019, China surpassed the United States to become the largest source of international patent applications filed through WIPO, and the number of international patent applications in China once again reached first place in the world in 2020 (PIRS 2021). However, the quality of innovation in China is not high, and the development of most core technologies still lags far behind that of developed countries (Cai and Yu, 2017). The "Stuck Neck" problem of core technology seriously restricts the safe development of China's economy. Therefore, how encouraging enterprises to improve GTI in quantity and quality is of great significance for China's transformation into an innovation power.

As a public good, the environment has the characteristics of non-competitive consumption and non-exclusive income, so "free riding" behavior often occurs (Zhang et al., 2022). At the same time, compared with traditional innovation, the spillover effect of GTI will also make the enterprises' innovation risk not match the innovation return, or even the innovation income is lower than the innovation input (Wang et al., 2020). Therefore, it is difficult for enterprises to independently carry out GTI relying only on the resource allocation role of the market (McGartland et al., 2017). Market failures necessitate government intervention. Governments and relevant organizations have issued a series of policies or treaties related to environmental protection, such as the *International Environmental Protection Convention*, *the Paris Agreement*, *the Kyoto Protocol*, *etc.* The government requires enterprises to comply with environmental protection laws and regulations by using administrative orders and punishing enterprises that violate the corresponding standards. The deterrent effect of punishment is the guarantee for the effective implementation of those environmental policies (Wang et al., 2018). However, due to information asymmetry and limited government administrative resources, only a part of environmental violations can be detected (Ayres and Braithwaite, 1995), which poses a huge challenge to regulation. Studies have found that the peer enterprises and the penalized enterprises face similar living environments and have similar business structures, so the spillover of the deterrent effect of penalties may also affect the peer enterprises with potential violation motives (Wang et al., 2019). Therefore, deterring enterprises with potential violations is the key to solving the environmental regulatory dilemma and realizing incentives for GTI. Based on this, this article attempts to answer the following questions: Can environmental administrative penalties of penalized enterprises deter peer enterprises? Will it improve the GTI capabilities of peer enterprises? What is the mechanism?

In previous literature, the study of environmental administrative penalties mainly focused on the impact on penalized enterprises. Environmental administrative penalties deter penalized enterprises (Hall, 2022). The penalties would significantly increase corporate audit costs (Xin et al., 2022), reduce corporate cash flows (Ding et al., 2022), increase debt costs (Ding et al., 2021), and promote voluntary disclosure of environmental information (Ding et al., 2019). In addition, self-disclosure of penalty information prevents the decline in the company's stock market return (Ding et al., 2020). In terms of enterprise environmental management, environmental administrative penalties would inhibit enterprises' greenwashing behavior (Sun and Zhang, 2019), reduce the number of days of violations (Nadeau, 1997), and improve environmental performance (Earnhart, 2004). With further research, scholars start to study the peer effect of environmental administrative penalties. It is found that environmental administrative penalties will promote environmental protection investment in the peer enterprises (Wang et al., 2020), and can also promote environmental governance in the process and outcome dimensions of other enterprises in the same industry (Chen et al., 2021). In addition, academia has been paying attention to environmental regulation and corporate GTI for a long time. Previous literature mainly focuses on macro-level environmental regulation and tests the Porter Hypothesis (George et al., 2017; Ramanathan et al., 2017). With further research, scholars realize that the innovation incentive effects of different environmental regulations may be different, so they classify environmental regulations and discuss the different innovation incentive effects of different environmental regulations (Ye et al., 2018; Hua et al., 2022). Further, there is literature that classifies GTI (Tao et al., 2021).

According to the review of previous literature, it is found that there are few studies on the innovation incentive effect of environmental administrative penalties, and the mechanism of the impact of environmental administrative penalties on peer enterprises' GTI is not clear. Moreover, the research on the influencing factors of technological innovation mainly focuses on the quantitative dimension, and there is only a few GTI research involving the quality dimension. After identifying this gap, this paper defines other enterprises in the same industry as the penalized enterprises as peer enterprises and divides the GTI capabilities of enterprises into two dimensions: quantity and quality. The number of green patent applications is used to indicate the quantity of GTI, and the knowledge breadth of green patents is used to indicate the quality of GTI. This study selects the data of Chinese listed companies in the heavy pollution industry in Shanghai and Shenzhen A-shares from 2016–2020 as the research sample. First, a fixed effects model is selected by the Hausman test to empirically analyze the effects of environmental administrative penalties on the quantity and quality of peer enterprises' GTI, respectively. The findings show that environmental administrative penalty significantly promotes the quantity and quality of peer enterprises' GTI. Its robustness is confirmed by replacing the explanatory variables, Heckman's two-stage model, negative binomial model, and panel Tobit model, and it also solves possible endogeneity problems by employing the dynamic system GMM model. After that, the internal and external factors of environmental administrative penalties affecting the GTI capabilities of peer enterprises are analyzed in three aspects: different perspectives of environmental administrative penalties, competitiveness heterogeneity of penalized enterprises, and property rights heterogeneity of peer enterprises. Additionally, we explore the moderating effect of financing constraints on the relationship between the environmental administrative penalties and peer enterprises' GTI capabilities. And it is found that financing constraints act as a moderator of disincentives. After summarizing the above findings, this study provides policy suggestions.

The contributions are mainly reflected in the following aspects. First, considering that the effectiveness of environmental administrative penalties on potential non-compliant enterprises has not been explored to a large extent, and the relevant empirical evidence is lacking, this paper studies the incentive effect of environmental administrative penalties on GTI from the perspective of peer effect. It enriches the academic community's understanding of the peer effect of environmental administrative penalties. Second, considering that the number of patent applications cannot fully represent the GTI capabilities of enterprises, this paper divides the GTI capabilities into two aspects: the quantity and quality of green patent applications, and analyses whether the GTI capabilities of peer enterprises can produce substantial improvement by environmental administrative penalties. It makes the research field of GTI more detailed and provides Chinese suggestions for the strategic deployment of high-quality GTI in the world. Third, considering that most of the previous literature only studies whether enterprises are subject to environmental administrative penalties, and most of the heterogeneity analysis only considers the penalized enterprises, this paper analyzes the heterogeneity from three perspectives: the diversity of penalty, the competitiveness of the penalized enterprises, and the property rights of peer enterprises. In addition, combined with the actual scenario of enterprises carrying out GTI, this paper further tests the moderating effect of financing constraints. Compared with previous literature, this paper has a more detailed research perspective, which provides a theoretical basis for the implementation of environmental administrative penalty policies. In addition, the effective implementation of China's environmental administrative penalties has important reference value for other countries to formulate environmental policies and improve the GTI capability, especially in developing countries.

The remainder of this paper is organized as follows: Section 2 will carry out a theoretical analysis and put forward hypotheses. The data sources, the measurement of the variables, and the econometric models are introduced in Section 3. The descriptive statistics, the regression results, and the robustness tests are presented in Section 4. The heterogeneity analysis and further analysis are presented in Section 5 and Section 6, respectively. The final section provides the conclusions and suggests some policy implications.

2 Theoretical basis and hypothesis development

The peer effect originated in sociology, which refers to the phenomenon that the behavior of the individual is affected by group behavior to a certain extent and changes with the change of group behavior (Manski, 1993). Early research on peer effects focused on sociology, such as educational production (Zheng, 2015), family financial decisions (Brown et al., 2015), the development of academic achievement in early adolescence (Hou et al., 2018), and criminal behavior (Walters, 2018). With further research, the peer effect has become a hot topic in finance, economics, and management. The research scope of the peer effect extends to enterprises. The behavior of enterprises is not only affected by their economic interests but also by other enterprises with similar status and characteristics, resulting in changes in their decision-making and behavioral results (Zhu et al., 2021). The existing study of the corporate peer effect found that there are significant peer effects in corporate finance and governance decisions such as information disclosure decisions (Seo, 2021), corporate governance (Fairhurst and Nam, 2018), financial decisions (Liu et al., 2022), employee welfare policies (Rind et al., 2021), investment decisions (Wang et al., 2022), and violations (Lu and Chang, 2018). In terms of the peer effect of environmental administrative penalties, Wang Yun et al. (2020) introduce the Deterrent Theory of punishment, empirically analyze the impact of environmental administrative penalties on the environmental protection investment of the peer enterprises, and find that environmental administrative penalties will produce a deterrent effect through the peer influence path. Chen et al. (2021) divide environmental administrative penalties into two aspects: penalty frequency and penalty intensity, and empirically analyze their impact on environmental governance in the process and outcome dimensions of other enterprises in the same industry. It is confirmed that environmental administrative penalties also have a deterrent effect on peer enterprises in the same industry.

In the context that all enterprises in the community are subject to environmental supervision, the peer enterprises will consciously pay attention to and follow the behavior of penalized enterprises to avoid the costs and risks of independent decision-making (Manski, 2000). Lieberman and Asaba (2006) pointed out that the reason for the peer effect of corporate decision-making behavior is to obtain decision-related information and maintain its competitive advantage. Zhu et al. (2021) also believe that compared with traditional decision-making behaviors, technological innovation has the characteristics of high risk, high investment, uncertain return period, and large potential benefits, so its dependence on information and market competition demand is greater. In addition, Li and Zhong (2019), and Zeng et al. (2020) also analyze the internal mechanism of the peer effect of enterprise decision-making from two types of motivations: information acquisition and competitive demand. The impact of environmental administrative penalties on peer enterprises can also be analyzed from these two aspects. On the one hand, environmental administrative penalties for companies that violate environmental regulations send out a deterrent signal through the communities, which may inform peer enterprises about the consequences and costs of engaging in similar environmental behavior (Wang et al., 2019). On the other hand, in order to maintain their reputation and respond to competitive pressures, companies will imitate the behavior of other individuals (Lu et al., 2017). To this end, this paper introduces Deterrence Theory and Competition Theory to analyze the impact of environmental administrative punishment on the GTI capability of peer enterprises.

According to the Deterrence Theory, penalties deter potential offenders by punishing the defendant so that they realize that the costs of crime outweigh the benefits and thus give up committing crimes (Wei and Song, 2006). At the same time, classical criminology also argues that even the most minor punishment will have a deterrent effect when the penalty is determined (Beccaria, 2016). When a penalized enterprise receives an environmental administrative penalty, it sends a deterrent signal to the peer enterprises that the government's environmental regulation will be more stringent. The business structure and production activities of the peer enterprises are similar to those of the penalized enterprises, so their production and operation processes are also at risk of being penalized. Their perception of the risks and costs of violating environmental regulations increases, and then they will check whether they are complying with environmental regulations based on the deterrent signal, weigh the costs of compliance and violation, and decide whether to carry out GTI. According to Hicks' Induced Innovation Theory, stricter environmental enforcement will lead to changes in product cost prices and higher environmental costs. When peer enterprises perceive that the sum of the high penalty cost and the cost of reputation loss due to environmental pollution is greater than the reduction of production cost due to risky violation, which means the innovation compensation effect of GTI exceeds the cost of violation (Guo et al., 2018), the peer enterprises cannot obtain competitive advantage through violation, then the optimal choice is the compliance strategy, and GTI will be used to solve the problem. Generally speaking, after the peer enterprises invest successfully in GTI, making pollution meet the environmental standards, they can be exempted from paying the emission exceedance fees or from environmental administrative penalties, thus reducing the economic burden. The government provides tax incentives, financial subsidies, priority procurement, and other policies, which will also partially compensate for the increased costs caused by GTI (Costa-Campi et al., 2017). As the social awareness of green environmental protection increases, consumers are more inclined to choose environmentally friendly products (Li et al., 2016), and GTI by enterprises can not only form a differentiated product advantage but also shape a good social image (Sarkar, 2013) and gain social benefits (Peng and Li, 2005). Therefore, enterprises are more inclined to carry out GTI. Therefore, based on the Deterrence Theory, the peer enterprises will take the initiative to carry out GTI because of the deterrence signal.

According to Competition Theory, in order to maintain a relatively competitive position or to counteract aggressive behavior by their peers, firms will pay close attention to the behavior of other firms (Wu et al., 2022). When firms are subject to environmental administrative penalties, they may engage in GTI (Cai et al., 2020) because of financial penalties, legal liability (Fernando, 2008; Pei et al., 2015), and damage to their social reputation (Polinsky and Shavell, 2000). Enterprises taking the lead in developing a certain technological innovation can protect their legitimate rights and interests by applying for patents, maintain the exclusivity of the technology, consolidate or even expand market share, and further improve their competitiveness (Ambec et al., 2013), so the competitiveness of the penalized enterprises increases. Enterprises in the same industry face a similar market environment, and there is competition for interests and resources between enterprises (Wu et al., 2022). When penalized enterprises carry out GTI to enhance their competitiveness, if the peer enterprises do not follow them, they will be in a backward competitive position, and their market share may decrease, which will adversely affect long-term development. In addition, when the market competition is fierce, commodity prices and profits are easily affected, which in

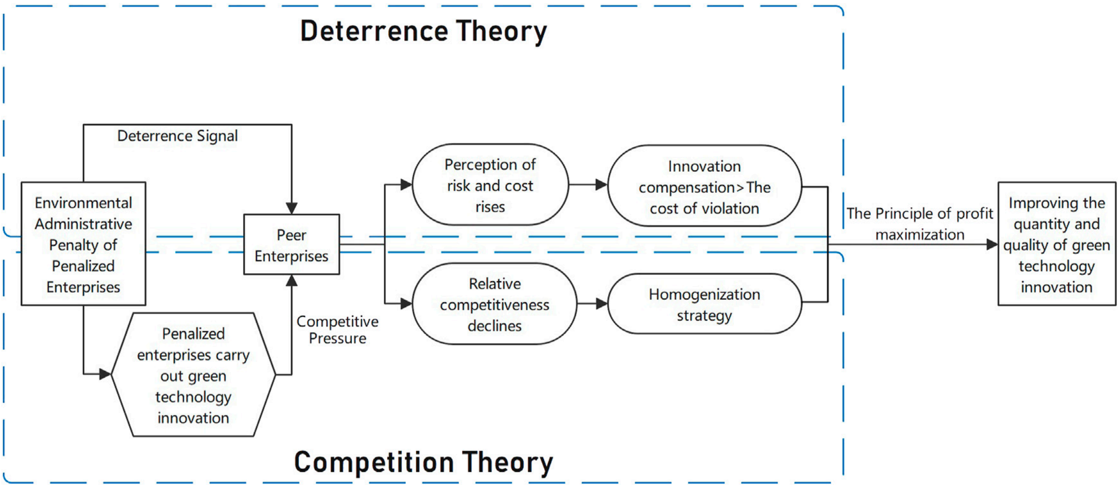

FIGURE 1
Theoretical analysis framework diagram.

turn leads to market fluctuations. In order to alleviate this situation, the peer enterprises often choose a homogenization strategy to match the penalized enterprises' behavior (Marvin et al., 2006), and also carry out GTI, thereby alleviating the intensity of competition, calming market volatility and reducing their risks (Marvin et al., 2006). Therefore, based on Competition Theory, the peer enterprises will passively carry out GTI due to competitive pressure.

In addition, the quantity of GTI cannot fully represent the level of independent innovation capabilities of peer enterprises (Zhang and Zheng, 2018). Low-quality GTI not only occupies the funds of peer enterprises, consumes a lot of scientific research resources, but also has difficulty meeting environmental supervision standards and improving market competitiveness. When the penalized enterprise is subject to an environmental administrative penalty, peer enterprises face external competitive pressure and deterrent signals, and their internal management must still follow the principle of profit maximization. However, the speculative behavior of lower-quality innovation cannot relieve the pressure of competition and the threat of penalties for peer enterprises. Therefore, the optimal strategy is to carry out high-quality patent research and development, improve the efficiency of patent technology transformation and application, maximize the use of limited resources to exert the compensation effect of technological innovation, and enhance their long-term competitive advantage (Jin et al., 2022). The theoretical analysis framework diagram is shown in Figure 1. Thus, the hypothesis is proposed as follows:

Hypothesis. The environmental administrative penalty of the punished enterprises can positively promote the quantity and quality of the peer enterprises' GTI.

3 Methodology

3.1 Sample and data collection

According to the 16 types of heavily polluting industries defined in *The Guidelines for Environmental Information Disclosure of Listed Companies (Draft for Comment)* issued by China in 2010, the listed companies in the heavily polluting industries in Shanghai and Shenzhen A-shares from 2016 to 2020 are selected as research samples. Then we omit listed firms that are marked "Special Treatment" (ST), marked "Particular Transfer," (PT) suspended listing, data missing, and subject to environmental administrative penalties. At last, we obtain 3,278 firm-year observations. The environmental administrative penalty data comes from the websites of the IPE, which is obtained through manual collection, and the enterprise GTI data comes from the Chinese Research Data Services (CNRDS) database, and the enterprise financial data comes from the China Stock Market and Accounting Research (CSMAR) database.

3.2 Variables and the measurement

3.2.1 Explained variable: Enterprises' GTI level

Two indicators are established to measure the enterprise GTI capabilities: quantity of GTI (ANGP) and quality of GTI (AQGP).

Quantity of GTI (ANGP): It is measured by the number of corporate green patent applications.

Quality of GTI (AQGP): It is measured by the quality of enterprise green patent applications. Drawing on the practice of

TABLE 1 Description of variables.

Category	Symbols	Descriptions
Explained variables	$ANGP_{i,t}$	Number of green patent applications of peer enterprises in year t
	$AQGP_{i,t}$	The quality of green patent applications of peer enterprises in year t is calculated by the knowledge width method
Explanatory variables	$Pind_{i,t-1}$	Environmental administrative penalty of penalized enterprises in year t-1, the ratio of the number of penalized enterprises to the total number of enterprises in the industry
	$ANGP_{i,t-1}$	Number of green patent applications of peer enterprises in year t-1
	$AQGP_{i,t-1}$	The quality of green patent application of peer enterprises in year t-1 is calculated by the knowledge width method
Control variables	SIZE	The natural logarithm of the firm's total assets
	DAR	Asset-liability ratio
	ROTA	Return on total assets
	FBSR	The shareholding ratio of the largest shareholder
	AFEE	Enterprise management expenses as a percentage of operating income
	OCF	Operating cash flow as a percentage of total assets
	SGR	The growth rate of operating profit
	AGE	Add 1 to the company's listing time and take the natural logarithm
	SOE	The nature of property rights, 1 for state-owned enterprises and 0 for non-state-owned enterprises
	Year	Year fixed effect

previous research (Akcigit et al., 2016; Zhang and Zheng, 2018), this paper uses the complexity of knowledge contained in a patent to measure the quality of green patent applications, which is defined as the knowledge breadth method. It refers to the calculation idea of industrial concentration, and weights the patent classification numbers at the group level. The bigger the variance of classification, the higher the quality of GTI.

3.2.2 Explanatory variable: Environmental administrative penalty

The environmental administrative penalty variable (Pind) refers to the methods of Kedia et al. (2015) and Valerie (2016) to measure the financial irregularities of enterprises in the industry. And it is expressed by the ratio of the number of penalized enterprises to the total number of enterprises in the industry.

3.2.3 Control variables

The corporate factors that affect GTI are mainly divided into three categories: corporate characteristics (Vogel, 2002), corporate financial performance (Cai and Li, 2017), and corporate governance characteristics (Qi et al., 2018), for which the following control variables are set. In terms of company characteristics, three variables are set: enterprise size (SIZE), listing age (AGE), and nature of property rights (SOE). In terms of the company's financial performance, four variables are set: asset-liability ratio (DAR), return on total assets (ROTA), operating cash flow (OCF), and growth rate of operating profit (SGR). In terms of corporate governance characteristics, two variables are set: the largest shareholder shareholding ratio (FBSR) and agency fees (AFEE). The specific index calculation method is shown in Table 1.

3.3 Econometric model

This study uses multi-year and multi-enterprise panel data for panel regression. The fixed-effect model is finally selected through the Hausman test. In order to test the impact of environmental administrative penalties on the quantity and quality of peer enterprises' GTI, model 1) for the number of green patent applications and model 2) for the knowledge width of green patent applications are established. Since the GTI may be affected by the previous period, the explanatory variables $ANGP_{i,t-1}$ and $AQGP_{i,t-1}$ are added to the model, respectively. The implementation of policies generally has the characteristic of lagging, so the environmental administrative penalty variable of the penalized enterprises with a lag of one period ($Pind_{i,t-1}$) is included in the models as an explanatory variable:

$$\boldsymbol{ANGP_{i,t} = \alpha_0 + \alpha_1 Pind_{i,t-1} + \alpha_2 ANGP_{i,t-1} + CV_{i,t} + Year + \varepsilon_{i,t}} \tag{1}$$

$$\boldsymbol{AQGP_{i,t} = \alpha_0 + \alpha_1 Pind_{i,t-1} + \alpha_2 ANGP_{i,t-1} + CV_{i,t} + Year + \varepsilon_{i,t}} \tag{2}$$

$CV_{i,t}$ represents the control variables. It controls the year fixed effect (Year). $\varepsilon_{i,t}$ is the random error term of the model.

TABLE 2 Descriptive statistics.

Variable	Mean	Median	Sd	Min	Max
ANGP	2.977	0.000	14.451	0.000	606.000
AQGP	1.309	0.000	6.220	0.000	237.703
Pind	0.336	0.328	0.145	0.000	0.800
SIZE	22.000	21.875	1.110	16.649	26.694
DAR	0.373	0.339	0.530	0.008	28.548
ROTA	0.047	0.053	0.546	−29.609	7.458
FBSR	33.409	30.750	14.078	5.000	89.090
AFEE	0.083	0.066	0.150	0.003	7.284
OCF	0.064	0.062	0.087	−1.686	2.222
SGR	0.070	0.048	1.853	−19.772	98.694
AGE	2.571	2.565	0.563	1.386	3.466
SOE	0.278	0.000	0.448	0.000	1.000

TABLE 3 Test results for the impact of the environmental administrative penalty on the peer enterprises' GTI.

Variable	(1)	(2)
	$ANGP_{i,t}$	$AQGP_{i,t}$
$Pind_{i,t-1}$	1.986**	0.858**
	(0.864)	(0.397)
$ANGP_{i,t-1}$	0.584***	
	(0.025)	
$AQGP_{i,t-1}$		0.666***
		(0.036)
CV	YES	YES
Constant	−14.75***	−6.788***
	(3.786)	(2.190)
Year	YES	YES
N	1,958	1,958
Adj-R2	0.8097	0.7794
F	73.64	42.71

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$. The t-statistics are in parentheses.

4 Empirical results and analysis

4.1 Descriptive statistics

The results of descriptive statistics are shown in Table 2. The average, median and maximum value of ANGP for the number of green patent applications are 2.977, 0.000 and 606.000, and the standard deviation is 14.451. The average, median and maximum values of AQGP for the quality of green patent apply are 1.309, 0.000, 237.703, and the standard deviation is 6.220, indicating that most companies have a low level of GTI, and the GTI levels of different companies vary significantly. So differentiated data makes research feasible. The average and median value of Pind for the environmental administrative penalty of penalized enterprises are similar, the average value is 0.336, indicating that in most industries, companies that are punished account for a minority. The minimum value is 0.000, indicating that there is an industry in which no company has been penalized throughout the year.

4.2 Test results

Table 3 shows the estimated results using the fixed-effect model based on model 1) and model (2). The core explanatory variable is the environmental administrative penalty variable of the penalized enterprises with a lag of one period ($Pind_{i,t-1}$), and the explained variables are the number of green patent applications ($ANGP_{i,t}$) and the quality of green patent applications ($AQGP_{i,t}$) of peer enterprises.

In the green patent application quantity model 1) and the green patent application quality model 2), the coefficients of the core explanatory variable of environmental administrative penalty for penalized enterprises ($Pind_{i,t-1}$) are positive, and significant at the 5% level, indicating that the environmental administrative penalty of penalized enterprises can not only promote the increase of the number of green patent applications of peer enterprises but also promote the improvement of the quality of patent applications of peer enterprises. The hypothesis has been verified. It indicates that when penalized enterprises are subject to environmental administrative penalties, peer enterprises will perceive their possible illegal risks due to similar business structures (Wang et al., 2019). At the same time, the relevant response measures of the penalized enterprises also put competitive pressure on the peer enterprises and affect their competitive position (Machokoto et al., 2021). And companies tend to believe that other companies have superior information and thus prefer to follow the decisions of other companies, so peer companies will accordingly carry out GTI and improve their own GTI level (Machokoto et al., 2021). On the one hand, peer enterprises' GTI will bring first-mover advantage incentives to themselves, enabling them to obtain environmental protection benefits as well as social benefits. On the other hand, the environmental administrative penalty for penalized enterprises provides a clearer innovation direction for peer enterprises and improves the efficiency and quality of technological innovation (Liu et al., 2020). Therefore, it will improve the efficiency and quality of their technological innovation, thus achieving and maintaining their competitive position (Ali, 2021). The regression results also confirm the existence of strategic interaction among enterprises (Wu et al., 2022). The environmental protection decision-making of enterprise managers does not exist in isolation, but after observing other enterprises violated and punished, they compare the costs of compliance and illegality and then optimize their decision-making.

TABLE 4 Robust tests—Variable substitution.

Variables	Z-score normalization		Dummy variable setting	
	(1)	(2)	(3)	(4)
	$std\_ANGP_{i,t}$	$std\_AQGP_{i,t}$	$ANGP\_M_{i,t}$	$AQGP\_M_{i,t}$
$Pind_{i,t-1}$	0.137**	0.138**	0.325***	0.30***
	(0.0598)	(0.0639)	(0.086)	(0.083)
$std\_ANGP_{i,t-1}$	0.584***			
	(0.0254)			
$std\_AQGP_{i,t-1}$		0.666***		
		(0.0357)		
$ANGP\_M_{i,t-1}$			0.362***	
			(0.0263)	
$AQGP\_M_{i,t-1}$				0.31***
				(0.023)
CV	YES	YES	YES	YES
Constant	−1.106***	−1.162***	−1.772***	−1.87***
	(0.260)	(0.351)	(0.221)	(0.220)
Year	YES	YES	YES	YES
N	1,958	1,958	1958	1958
R2	0.8097	0.7794	0.2584	0.2153
F	73.64	42.71	72.88	61.85

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$. The t-statistics are in parentheses.

Besides, in the regression results, the explanatory variables of the GTI level lagging one period ($ANGP_{i,t-1}$ and $AQGP_{i,t-1}$) are all significantly positive at the 1% level, indicating that the GTI of the previous period can promote the improvement of the current GTI level.

4.3 Robust tests and endogenous test

4.3.1 Variable substitution

4.3.1.1 Z-score normalization

The main explanatory variable of this paper ($Pind_{i,t-1}$) is presented in the form of percentages. The explained variables ($ANGP_{i,t}$ and $AQGP_{i,t}$) are presented in the form of absolute value, and the standard deviation of them is large. In order to eliminate the dimensional relationship between the variables and make the data comparable, use the method of Z-score normalization to process the explained variables $ANGP_{i,t}$ and $AQGP_{i,t}$, and obtain the processed variables $std\_ANGP_{i,t}$ and $std\_AQGP_{i,t}$. The test results are shown in Table 4. The estimator of the core explanatory variable $Pind_{i,t-1}$ is still positive and significant, which is consistent with the results in the benchmark regression in Table 4, so the regression results after variable substitution are robust.

4.3.1.2 Dummy variable setting

Since the selection of different proxy variables to measure the GTI level of enterprises may have different effects on the estimation results, this paper refers to Zhang et al. (2022), setting dummy variables based on the median number of the quantity and quality of enterprise GTI to test the robustness. If the quantity of GTI of peer enterprises is greater than or equal to the median of all samples in the year, the dummy variable of the quantity of GTI (ANGP_M) is assigned to 1, which indicates that the number of green patent applications is high, otherwise it is assigned to 0, which indicates that the number of green patent applications is low. If peer enterprises' quality of GTI is greater than or equal to the median of all samples in the year, the dummy variable of the quality of GTI (AQGP_M) is assigned to 1, which means the enterprise has high GTI quality, otherwise it is assigned to 0, which means the enterprise has low GTI quality. After replacing the variables, the benchmark regression is conducted again, and the results are shown in columns (3)–(4) of Table 4. The coefficient of the core explanatory variable $Pind_{i,t-1}$ is positive and significant at the 1% level, so the results obtained are consistent with the benchmark regression and the results are robust.

TABLE 5 Robust tests—Model substitution.

Variables	Heckman's two-stage selection model				The negative binomial regression model	Panel Tobit model
	(1)	(2)	(3)	(4)	(5)	(6)
	$ANGP01_{i,t}$	$ANGP_{i,t}$	$AQGP01_{i,t}$	$AQGP_{i,t}$	$ANGP_{i,t}$	$AQGP_{i,t}$
$Pind_{i,t-1}$	1.041***	4.967*	1.090***	2.312*	1.609***	4.30***
	(0.279)	(2.681)	(0.279)	(1.362)	(0.358)	(1.118)
$ANGP01_{i,t-1}$	0.980***					
	(0.0651)					
$ANGP_{i,t-1}$		0.576***			0.082***	
		(0.0223)			(0.021)	
$AQGP01_{i,t-1}$			0.868***			
			(0.0655)			
$AQGP_{i,t-1}$				0.662***		0.674***
				(0.0345)		(0.016)
IMR		2.598**		1.802***		
		(1.006)		(0.627)		
CV	YES	YES	YES	YES	YES	YES
Constant	−6.677***	−35.40***	−7.496***	−19.51**	−0.212***	−30.84
	(0.789)	(12.45)	(0.793)	(8.054)	(1.111)	(3.048)
Year	YES	YES	YES	YES	YES	YES
N	1,958	842	1,958	755	1,958	1,958
R2	0.1892	0.8216	0.1734	0.7928	0.0842	
F	-	80.03	-	38.70		
alpha					2.553	
					(2.13,3.06)	
LR						26.31***

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$. The t-statistics are in parentheses. In the Heckman two-stage selection model, R2 is reported as Pseudo R2 in the first and third columns and as Adj-R2, in the second and fourth columns. Others are reported as Adj-R2. In the negative binomial regression model, R2 is reported as Pseudo R2.

4.3.2 Model substitution

4.3.2.1 Heckman two-stage selection model

There may be sample selectivity bias in this paper. On the one hand, the green patent application data are all from the CNRDS database, but the CNRDS database only includes the green patent data of Shanghai and Shenzhen A-share listed firms, and it is difficult to obtain green patent data of heavily polluting enterprises other than Shanghai and Shenzhen A-shares. On the other hand, the sample data contains both high-quality GTI observations and low-quality GTI observations, but a high-quality GTI observation of zero does not cause bias only when it occurs randomly, but whether to carry out high-quality GTI activity is a decision made by the firm after considering the internal and external environment. Therefore, both quantitative and qualitative GTI variables are subject to selective bias. The Heckman two-stage selection model can be used to solve the sample selectivity bias problem, so it is used for the robust test. Firstly, the first stage green patent decision model is constructed for Probit regression, which mainly tests the correlation between environmental administrative penalties of penalized enterprises and the level of GTI of peer enterprises, and then calculates the inverse Mills ratio (IMR) according to the first-stage model. The second stage is a regular regression equation with the additional inverse Mills ratio (IMR). When Probit>0, ANGP and AQGP will only be observed, so enterprises with $ANGP_{i,t}$ >0 and $AQGP_{i,t}$ >0 > 0 are selected as samples for the second-stage OLS regression. The test results are shown in columns (1)–(4) of Table 5. The IMR coefficient is non-zero and significant at the 5% level, indicating that the sample does have a self-selection problem. After adding IMR for model correction, the estimates of the core explanatory variable $Pind_{i,t-1}$ remain positive and are significant at the 1% level for both the GTI quantity model and the GTI quality model, consistent with the results in the benchmark regression in Table 5, so the results are robust.

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4.3.2.2 Negative binomial regression model

As one of the explained variables in this paper, the quantity of GTI is measured by the number of green patents applied by enterprises in the year, which is a count variable and conforms to the Poisson distribution. However, the indicator of the number of green patent applications is excessively scattered and its expectation and variance have large differences, for which a negative binomial model is chosen for estimation. Meanwhile, the number of green patent applications has a large number of zero values in the year, and the zero-inflated negative binomial model should be used theoretically, but the p-value of the Vuong test statistic is not significant, so the zero-inflated negative binomial regression is rejected, and the standard negative binomial regression model is selected for robustness testing. The test results are shown in column (5) of Table 5. The parameter estimate of α is 2.55, while the 95% confidence interval of α is (2.13,3.06), so it is appropriate to use the standard negative binomial regression. Meanwhile, the estimate of the core explanatory variable $Pind_{i,t-1}$ remains positive and significant at the 1% level, which is consistent with the benchmark regression results in Table 5, so the results are robust.

4.3.2.3 Panel Tobit model

Since one of the explained variables, the GTI quality index, is calculated by the knowledge breadth method, and its value is positive and approximately continuously distributed, but there are a large number of zero values, which is a lower bounded problem, so the panel Tobit regression is used to test the robustness of the GTI quality model. The results of the test are shown in column (6) of Table 5, and the p-value of the LR test is 0.000, indicating that the use of the panel Tobit model is appropriate. In addition, the coefficient of the core explanatory variable $Pind_{i,t-1}$ is estimated to be positive with a significance level of 1%, which is consistent with the results of the benchmark regression in Table 5, so the results are robust.

4.3.3 Endogenous test

There is a mutually causal relationship between GTI and the profitability of enterprises. On the one hand, capital is an important factor for enterprises to carry out GTI, and enterprises with good profitability can obtain more capital from the profit, while the level of profitability is also a factor that external investors need to consider when investing in enterprises. On the other hand, it is known from the theory of technological innovation that technological innovation is a strong guarantee for the core competitiveness of enterprises. Green patents generated by enterprises' high-quality GTI activities are easy to be examined by patent examiners, and their exclusivity and practicality are strong, which are more conducive to converting it into a product to obtain technology monopoly profits, thereby improving enterprises' profitability. Given that the dynamic system GMM model can solve the endogeneity problem caused by reverse causality, the one-period lag of the SGR variable is selected as an instrumental variable for testing, and the IMR is added to correct the sample selectivity bias. The results are shown in Table 6. From the regression results of the test, the p-values of AR 1) are both less than 0.05 and the p-values of AR 2) are both greater than 0.1, indicating that the original hypothesis of "all instrumental variables are valid" (p-value greater than 0.1) cannot be rejected, which proves that the instrumental variables do not have over-identification problem and pass the over-identification test. In column (1), the $Pind_{i,t-1}$ variable of the GTI quantity model is significantly positive at the 10% level, and in column (2), the $Pind_{i,t-1}$ variable of the GTI quality model is also significantly positive at the 10% level, so the test results are consistent with the benchmark test, indicating that after considering the endogeneity of the mutual causality between GTI and profitability of enterprises, the environmental administrative penalties imposed on enterprises do significantly improve the quantity and quality of GTI of the peer enterprises, so the results are robust.

TABLE 6 Endogenous test.

Variables	**Dynamic system GMM model**	
	(1)	**(2)**
	$ANGP_{i,t}$	$AQGP_{i,t}$
$Pind_{i,t-1}$	5.800*	3.873*
	(3.329)	(2.205)
$ANGP_{i,t-1}$	0.632**	
	(0.286)	
$AQGP_{i,t-1}$		0.921***
		(0.188)
IMR	4.437***	2.830***
	(1.214)	(0.570)
CV	YES	YES
Constant	−103.4	−41.54
	(75.70)	(155.3)
Year	YES	YES
N	1,958	1,958
Number of code	858	858
p-values of AR (1)	0.0149	0.0022
p-values of AR (2)	0.2837	0.3749
p-values of the Sargan test	0.2699	0.5242

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$. The t-statistics are in parentheses.

TABLE 7 Test results for the impact of heterogeneous environmental administrative penalty on the peer enterprises' GTI.

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	$ANGP_{i,t}$	$AQGP_{i,t}$	$ANGP_{i,t}$	$AQGP_{i,t}$	$ANGP_{i,t}$	$AQGP_{i,t}$
$Pind\_num_{i,t-1}$	4.881***	2.396***				
	(1.796)	(0.853)				
$Pind\_str_{i,t-1}$			4.005**	1.861**		
			(1.584)	(0.730)		
$Pind\_dep_{i,t-1}$					4.020**	1.950**
					(1.959)	(0.912)
$ANGP_{i,t-1}$	0.584***		0.584***		0.584***	
	(0.0254)		(0.0254)		(0.0254)	
$AQGP_{i,t-1}$		0.666***		0.666***		0.666***
		(0.0356)		(0.0357)		(0.0356)
CV	YES		YES		YES	
Constant	−14.47***	−6.691***	−14.62***	−6.753***	−14.61***	−6.760***
	(3.712)	(2.151)	(3.730)	(2.164)	(3.770)	(2.185)
Year	YES		YES		YES	
N	1,958	1,958	1,958	1,958	1,958	1,958
Adj-R2	0.81	0.7797	0.8098	0.7796	0.8098	0.7795
F	73.75	42.40	74.28	42.44	73.46	42.86

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$. The t-statistics are in parentheses.

5 Heterogeneity analysis

5.1 The impact of the heterogeneous environmental administrative penalty on the peer enterprises' GTI

The environmental administrative penalty is diverse in frequency, severity, and administrative level of the penalty implementers, and the deterrent force produced by different penalty results varies. To this end, the environmental administrative penalty variables of penalized enterprises are constructed according to these three dimensions to study the impact on the quantity and quality of peer enterprises' GTI when penalized enterprises are subject to heterogeneous environmental administrative penalties.

The construction of the frequency variable of environmental administrative penalty for penalized enterprises (Pind_num) refers to the study of Valerie (2016). Taking the median of the frequency of environmental administrative penalties imposed on penalized enterprises in the industry, Pind_num is represented by the ratio of the number of companies with penalty frequency greater than the median to the total number of companies in the industry. The construction of the severity variable of environmental administrative penalty for penalized enterprises (Pind_str) refers to the study of Chen et al. (2021). Assign corresponding points to each environmental administrative penalty method, and then add the total score to get the severity of the environmental administrative penalty for each enterprise. The higher the score, the stronger the severity of the environmental administrative penalty the enterprise is subjected to. Taking the median of the penalized enterprises in the industry, Pind_str is represented by the ratio of the number of companies with penalty severity greater than the median to the total number of companies in the industry. A similar method is used to construct the administrative level variable of the penalty implementers (Pind_dep). Assign points to the penalty imposed on enterprises from different levels of administration. The prefecture-level city and below administrations are counted as 1 point, the provincial-level administrations are counted as 2 points, and the provincial-level administrations are counted as 3 points. And then add up to get the administrative level of the penalty implementers for each enterprise. Taking the median of the penalized enterprises in the industry, Pind_dep is represented by the ratio of the number of companies with a penalty administrative level greater than the median to the total number of companies in the industry. Substitute the above three variables for the variable $Pind_{i,t-1}$ in model 1) and model 2) respectively, and also take a lag of one period. The test results are shown in Table 7.

In Table 7, the coefficients of $Pind\_num_{i,t-1}$、 $Pind\_str_{i,t-1}$ and $Pind\_dep_{i,t-1}$ in model 1) and model 2) are all positive, and the coefficient of $Pind\_num_{i,t-1}$ is significant at the 1% level, the coefficients of $Pind\_str_{i,t-1}$ and $Pind\_dep_{i,t-1}$ are both significant at the 5% level. This result further verifies the hypothesis of this paper, that is, the environmental administrative penalty of penalized enterprises can positively promote the quantity and quality of peer enterprises' GTI. The higher the frequency of the penalty, the greater the severity of the penalty, and the higher the administrative level of the penalty implementer, the stronger the positive promotion effect. It may be because the actual effect of the environmental administrative penalty depends on the scale of the penalty (Qi et al., 2016). Maintaining a higher frequency or a more severe penalty method makes environmental administrative penalties more deterrent (Xu et al., 2020), and the penalty of higher-level implementers also makes the information spread more widely, so the impact effect will be greater.

Specifically, in terms of penalty frequency, as penalized enterprises receive more environmental administrative penalties, the cost of breaking the law will also increase, forcing them to innovate green technologies (Cai et al., 2020) and creating competitive pressure on peer enterprises. At the same time, these penalties are transmitted to society as risk information again and again. The stronger the deterrent signal received by peer enterprises, the stronger their perception of the risk of being penalized and the cost of noncompliance (Ling et al., 2022), forcing them to check whether they can meet regulatory requirements and improve their GTI. In terms of the severity of the environmental administrative penalty, the deterrent effect of the penalty will vary depending on the means of penalties (Shimshack, 2014). The more severe the environmental administrative penalty, the greater the deterrent effect on the penalized enterprises. According to the strong Porter Hypothesis, penalized enterprises will innovate green technology (Miao et al., 2019), and improve their competitiveness. The competitive pressure on peer enterprises increases as the severity of the environmental administrative penalties increases. The disclosure of penalty information also increases the deterrent signals received by peer enterprises as the severity of environmental administrative penalties increase and reduces the information asymmetry between enterprises (Yan et al., 2022). For long-term development, the peer enterprises will also implement green strategies in the face of increasingly strong competitive pressure and deterrent signals, and improve their own GTI level. Regarding the administrative level of the penalty implementer of environmental administrative penalty, the environmental administration at all levels has different powers to impose fines and penalties. The higher the administrative level, the higher the amount of fine that the department can directly make, so the greater its deterrent effect (Xu et al., 2020). Besides, the information disclosure of enterprises that are subject to environmental administrative penalties by the environmental protection department at or above the provincial level is mandatory. The greater the information spreads, the greater the impact. Therefore, the higher the administrative level of the penalty implementer, the greater the deterrent effect on peer enterprises (Ling et al., 2022).

TABLE 8 Test results for the impact of the heterogeneous penalized enterprises on the peer enterprises' GTI.

Variable	(1)	(2)
	$ANGP_{i,t}$	$AQGP_{i,t}$
$Pcpt\_B_{i,t-1}$	−0.957	−0.765
	(3.350)	(1.470)
$Pcpt\_S_{i,t-1}$	10.79*	5.812**
	(6.182)	(2.944)
$ANGP_{i,t-1}$	0.585***	
	(0.0257)	
$AQGP_{i,t-1}$		0.667***
		(0.0354)
CV	YES	YES
Constant	−13.71***	−6.288***
	(3.577)	(2.079)
N	1,958	1,958
Year	YES	YES
R2	0.8097	0.7796
F	71.28	42.02

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$. The t-statistics are in parentheses.

In addition to receiving deterrent signals, peer enterprises will also be subject to competitive pressure from penalized enterprises, so peer enterprises will also be forced to improve their GTI level. All in all, the more frequent the penalty, the more severe the penalty, and the higher the administrative level of the penalty implementer, it will all send a signal to the society that environmental law enforcement is intensified, and the deterrent signal and competitive pressure received by peer enterprises will be stronger. When the compensation effect of GTI exceeds the cost caused by illegal activities, it provides the impetus for the sustainable innovation activities of peer enterprises, thereby improving their own GTI level (Porter, 1991).

5.2 The impact of the heterogeneous penalized enterprises on the peer enterprises' GTI

The deterrent effect of environmental administrative penalties will vary due to the different competitiveness of the penalized enterprises. Using the method of Wang et al. (2020), the market share is used to measure the market competitiveness of the enterprise, where the market share is equal to the ratio of the company's operating income to the total operating income of the industry. The ratio of the number of punished enterprises in the top 10% and the bottom 10% of the market share in the industry to the total number of enterprises in the same industry is taken to represent the environmental administrative penalty variables of highly competitive (Pcpt_B) and weakly competitive (Pcpt_S) companies, respectively. Replace the $Pind_{i,t-1}$ variable in model 1) and model 2) with these two variables, and also take a lag of one period. The test results are shown in Table 8.

In columns (1) and (2), the coefficient of the $Pcpt\_S_{i,t-1}$ variable is positive and significant at the 10% level, the coefficient of $Pcpt\_B_{i,t-1}$ variable is not significant. It shows that the environmental administrative penalty of the weakly competitive enterprises will positively promote the peer enterprises' quantity and quality of the GTI, while the environmental administrative penalty of highly competitive companies has no significant impact. This result may be due to the fact that there are a large number of weakly competitive enterprises scattered in the industry. Such enterprises generally have relatively poor resource allocation capabilities (Du and Guo, 2021), lack funds and scientific research resources, and are difficult to reduce emissions by environmental regulations. Besides, the degree of information disclosure is low, and the cost of supervision by the environmental protection department is higher. The environmental protection department is more inclined to supervise enterprises with strong competitiveness, which leads to enterprises with weak competitiveness becoming invisible sources of pollution. When companies with weak competitiveness are subject to environmental administrative penalties, it will release a signal of increased environmental enforcement (Wang et al., 2020). Companies with strong competitiveness are punished to send a signal to society that environmental enforcement is routine, and its deterrent effect may be relatively weak. Moreover, competitive enterprises can give full play to the advantages of capital and management in the face of environmental administrative penalties, actively develop and introduce innovative technologies, so as to easily grasp the core technologies and market opportunities, and obtain comparative advantages in market competition (Bi et al., 2018). When they are punished because of environmental problems and then carry out GTI, the competitive pressure in the industry is not enough to promote the peer enterprises to carry out GTI.

5.3 The impact of the environmental administrative penalty on the GTI of heterogeneous peer enterprises

For peer enterprises with potential violations, the innovation behaviors of state-owned enterprises and non-state-owned enterprises are quite different. Therefore, it is necessary to consider the property rights of peer enterprises. According to the study by Wang et al. (2021), classify the sample according to state-owned enterprises and non-state-owned enterprises to form two subsamples, and the property rights variable (SOE) in the control variable is deleted. Test the differences in the sensitivity to environmental administrative penalties of the peer enterprises with heterogeneous property rights. The test results are shown in Table 9.

TABLE 9 Test results for the impact of the environmental administrative penalty on the GTI of heterogeneous peer enterprises.

Variable	SOE		Non-SOE	
	(1)	(2)	(3)	(4)
	$ANGP_{i,t}$	$AQGP_{i,t}$	$ANGP_{i,t}$	$AQGP_{i,t}$
$Pind_{i,t-1}$	3.501	1.555	1.308**	0.529*
	(2.754)	(1.117)	(0.566)	(0.276)
$ANGP_{i,t-1}$	0.586***		0.448***	
	(0.0271)		(0.0319)	
$AQGP_{i,t-1}$		0.678***		0.464***
		(0.0293)		(0.0425)
CV	YES	YES	YES	YES
Constant	−24.68***	−11.56***	−9.633***	−4.461***
	(8.205)	(4.279)	(1.920)	(1.036)
Year	YES	YES	YES	YES
N	510	510	1,448	1,448
R2	0.8754	0.8461	0.3773	0.3676
F	59.13	75.45	38.17	21.19

$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$. The t-statistics are in parentheses.

According to Table 9, the coefficients of the variable $Pind_{i,t-1}$ in the quantity model and quality model of non-state-owned enterprises are both positive and significant at the level of 5% and 10%, respectively. The coefficients of the variable $Pind_{i,t-1}$ of state-owned enterprises are not significant. It shows that the environmental administrative penalty of penalized enterprises has no significant impact on the quantity and quality of state-owned peer enterprises' GTI, but it can significantly promote the non-state-owned peer enterprises' GTI. This result may be due to the fact that state-owned enterprises have some internal linkage with the government, they understand and respond to policies timely and accurately, and can deal with the corresponding environmental risks in advance (Yang et al., 2021). What's more, their political rights can make them less constrained by the policies (Lu et al., 2022). Moreover, state-owned enterprises are to some extent sheltered by the government, which sometimes tolerates irresponsible behavior by state-owned enterprises, and they have less incentive to take on social responsibility to accomplish certain economic goals (Ali et al., 2019). State-owned enterprises even have monopoly power over the industry, and their political characteristics and monopoly status may lead to their lack of interest in market demand and R&D investment (Zhang and Xu, 2022). Compared with non-state-owned enterprises, the leadership of state-owned enterprises is generally appointed by the government (Lu et al., 2014), and the term of employment is short (Yin and Zhang, 2016), so the personal interests of managers have little to do with the long-term development of the enterprise. In addition, the governance characteristics of the rigid management system and low management efficiency of state-owned enterprises also weaken the incentive effect on the manager, thereby causing an erosion effect on technological innovation (Zhang and Xu, 2022). Therefore, when penalized enterprises are subject to environmental administrative penalties, the deterrent effect and competitive pressure are not enough to affect the state-owned peer enterprises' GTI. The manager of state-owned enterprises pays more attention to the short-term effects of development strategies and prefers short-term investment projects, and will not choose GTI projects with long return periods and high risks (Wang et al., 2018), which will also have a crowding-o effect on GTI. Non-state-owned enterprises do not have the protection of local governments and are in a highly competitive market environment, so they are more sensitive to deterrent signals and competitive pressures. In order to survive in the fierce market competition, they must rely on the long-term benefits of GTI to maintain or even increase its relative competitiveness.

6 Further analysis: The moderating effect of peer enterprises' financing constraints

The GTI of peer enterprises is easily restricted by their financing constraints in the process of development (Ji, 2018). The capital use cycle of innovation activities is long, the capital demand is large, and the profitability is also unstable. At the same time, the incompleteness of the capital market, the asymmetry of information, and the existence of agency problems make peer enterprises face serious financing constraints, which in turn affects the GTI. This section examines the moderating effect of financing constraints in the process of environmental administrative penalty affecting the peer enterprises' GTI.

Among the measurement methods of financing constraints (FC), the SA index constructed by Hadlock and Pierce (2010) can fully reflect the level of financing constraints of enterprises. The SA index does not contain endogenous variables, which can avoid measurement bias and subjectivity problems existing in other methods, and is widely used in various studies (Wu and Huang, 2017).

This paper uses the absolute value of the SA index to measure the level of financing constraints of peer enterprises. When the absolute value of the SA index is larger, it indicates that the financing constraints of peer enterprises are greater (Gu and Zhu, 2021). In order to examine the moderating effect of financing constraints on environmental administrative penalty and peer enterprises' GTI, the following model is constructed:

TABLE 10 Test results for the moderating effect of financing constraints.

Variable	(1)	(2)
	$ANGP_{i,t}$	$AQGP_{i,t}$
$Pind_{i,t-1}$	54.74***	27.97***
	(13.98)	(7.071)
$FC_{i,t}$	4.209***	1.920***
	(1.448)	(0.734)
$Pind_{i,t-1}*FC_{i,t}$	−13.38***	−6.886***
	(3.570)	(1.806)
$ANGP_{i,t-1}$	0.580***	
	(0.00703)	
$AQGP_{i,t-1}$		0.661***
		(0.00868)
CV	YES	YES
Constant	−32.26***	−14.76***
	(6.155)	(3.115)
Year	YES	YES
N	1,958	1,958
R2	0.8119	0.7812
F	698.35	582.27

$*p < 0.1$, $**p < 0.05$, $***p < 0.01$. The t-statistics are in parentheses.

$$\begin{aligned} ANGP_{i,t} = \alpha_0 + \alpha_1 Pind_{i,t-1} + \alpha_2 FC_{i,t} + \alpha_3 Pind_{i,t-1}{*}FC_{i,t} \\ + \alpha_4 ANGP_{i,t-1} + CV_{i,t} + Year + \varepsilon_{i,t} \end{aligned} \tag{3}$$

$$\begin{aligned} AQGP_{i,t} = \alpha_0 + \alpha_1 Pind_{i,t-1} + \alpha_2 FC_{i,t} + \alpha_3 Pind_{i,t-1}{*}FC_{i,t} \\ + \alpha_4 AQGP_{i,t-1} + CV_{i,t} + Year + \varepsilon_{i,t} \end{aligned} \tag{4}$$

The test results are shown in Table 10. Columns (1) and (2) are the test results of the moderating effect of financing constraints on the relationship between environmental administrative penalty and the quantity and quality of peer enterprises' GTI. The results show that the coefficient of the interaction term ($Pind_{i,t-1}$* $FC_{i,t}$) between environmental administrative penalty and financing constraints is significantly negative at the 1%level, which means that when peer enterprises face high financing constraints, the role of environmental administrative penalty in promoting the quantity and quality of their GTI will be weakened.

This is mainly because as the main influencing factor of technology innovation, capital is essential for enterprises to carry out GTI (Gu et al., 2021). Like other innovation activities, GTI activities are characterized by high investment, low return, and high risk, which require sufficient and stable financial support (Yu et al., 2021). The financing funds for enterprises' innovation activities mainly come from external funds provided by financial markets and internal funds generated from production and operation activities. Due to the information asymmetry between enterprises and external investors, investors are likely to set a large number of restrictive clauses for enterprises while investing funds, increasing the hidden financing costs of enterprises (Xu et al., 2021), which makes it more difficult for enterprises to obtain external funds for investment in GTI than other types of investments. In addition, when peer enterprises face high external financing constraints, they may turn to internal financing such as their funds to carry out GTI, and if their funds cannot meet the financial needs of GTI, it will also adversely affect GTI. When the lack of capital restricts the GTI decision of the peer enterprises, it also weakens their motivation to improve the quality of GTI (Deng et al., 2022). The peer enterprises will reduce the research and development of GTI projects (Yang and Xi, 2019), so both the quantity and quality of GTI will be affected, which leads to the weakened role of financing constraints in environmental administrative penalties promoting the quantity and quality of GTI.

7 Conclusion and policy implications

Based on the existing research results, this paper takes the listed companies of heavily polluting industries in Shanghai and Shenzhen A-share from 2016 to 2020 as the research sample, divides the GTI level into quantity and quality, and studies the impact of the environmental administrative penalty on the peer enterprises' GTI. Combined with empirical results, it is found that: 1) Environmental administrative penalty can significantly promote the quantity and quality of peer enterprises' GTI. 2) The diversity of environmental administrative penalties makes the deterrent effect of different penalties vary. The frequency of the penalty, the severity of the penalty, and the administrative level of the penalty implementer can positively promote the quantity and quality of peer enterprises' GTI. 3) The impact of the environmental administrative penalties on peer enterprises will vary due to the different characteristics of the penalized enterprises. Environmental administrative penalties of penalized enterprises with weak competitiveness can significantly promote the quantity and quality of peer enterprises' GTI, while the penalty of highly competitive companies has no significant effect. 4) The different property rights of peer enterprises also make their sensitivity to environmental administrative penalties different. The environmental administrative penalty can significantly promote the quantity and quality of GTI in non-state-owned peer enterprises but have no significant impact on state-owned peer enterprises. 5) When peer enterprises face high financing constraints, the effect of the environmental administrative penalties on the quantity and quality of peer enterprises' GTI will be weakened.

These findings provide the following policy implications: Governments should increase the mandatory disclosure of information on corporate environmental administrative penalties. Also considering that the frequency, severity, and administrative level of the penalty implementer of environmental administrative penalties have a significant contribution to the quantity and quality of GTI in the peer enterprises, the government should implement more severe environmental administrative penalties to maximize their deterrent effect. But the government's policymaking should not be "one size fits all." They should assess the competitiveness and the nature of the property rights of enterprises, and formulate more targeted policies. In addition, the government should also standardize and improve the financing mechanism of enterprises' GTI, alleviate the problem of capital demand in the process of transformation and upgrading of enterprises' green industries, stimulate the vitality of enterprise innovation, and avoid the occurrence of the "patent bubble" phenomenon.

This study may have some limitations as follows. First, the sample only includes listed companies, but environmental administrative penalties are not only imposed on listed companies, and environmental administrative penalties for non-listed companies can also be observed by the peer enterprises. Besides, the listed companies are easy to be monitored, so their impact on peer enterprises may not be the same as that of non-listed companies. Therefore, in future research, case studies can be used to analyze the impact of environmental administrative penalties imposed on non-listed companies, making the scope of the study as comprehensive as possible. Second, the period of the sample is 2016–2020, but enterprise GTI from research and development to patent application generally takes 3 years or even longer. What's more, China has implemented a stricter environmental protection law since 2015 and proposed to resolutely fight the nationwide battle to prevent and control pollution in 2018. Environmental supervision is increasing year by year, so the 5-year period can hardly reflect the long-term mechanism of the environmental administrative penalty. For this reason, the period of the sample should be broadened in future studies to better study the long-term governance mechanism of environmental administrative penalties.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: The Chinese Research Data Services (CNRDS) database, the China Stock Market and Accounting Research (CSMAR) database and the websites of the IPE.

Author contributions

All authors contributed to the study's conception and design. XC put forward the idea, designed the study, and reviewed the manuscript. Material preparation, data collection and analysis,

and the first draft of the manuscript were performed by MZ. All authors read and approved the final manuscript.

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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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R&D investment, financing constraints and corporate financial performance: Empirical evidence from China

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Enterprises are a deeply significant pillar of social and economic development. The excellent economic interests of enterprises play an essential role in promoting social and economic development. Business is a major innovation force in improving a country's independent innovation capacity, which in turn is a key factor in shaping its core competitiveness. As the fuel of technological innovation for enterprises, Research and development (R&D) can accelerate their development and enhance their competitiveness. By using Chinese A-share listed companies from 2007 to 2019 as a sample, this study attempts to examine the specific impact of R&D investment by Chinese companies on corporate performance. Key to the development of R&D activities, R&D investment is directly related to the source of funding, the quality of financing channels and the extent of financing restrictions. The current study explains why enterprise innovation cannot be separated from the input and support of capital, technology, professional talent and other factors from the perspective of enterprise financing constraints. By using Chinese A-share listed companies from 2007 to 2019 as a sample, the study not only examined the impact of R&D investment on corporate performance, but also considered specific mediating mechanisms and heterogeneity analysis of R&D investment on corporate performance. Finally, the study found a significant positive correlation between R&D investment and the performance of listed companies, and this positive correlation was more pronounced when funding constraints were lower. According to the study, mediation effect analysis shows that R&D investment can improve corporate performance by boosting total factor productivity. Additional research has also shown that higher levels of internal control quality can improve the boosting effect of R&D investment on corporate performance. Moreover, R&D investment by SOEs is more conducive to improving the performance of their enterprises than that of non-SOE enterprises. In addition, this study provides empirical evidence of the knowledge effect and positive externality of R&D investment for firms, examines the impact of R&D investment on corporate performance from the perspective of financing constraints, and enriches the related literature on R&D investment, financing constraints and corporate performance.

KEYWORDS

R&D investment, financing constraints, enterprise performance, mediating effect, internal control quality

1 Introduction

How to improve the performance of a business has long been a hot topic in the academic community. Numerous studies and practices show that corporate performance is affected by a number of factors, such as the industry environment and the company's internal operations. To maintain strong profitability, companies must improve their competitiveness. In an increasingly competitive environment in the capital markets, the innovation and R&D of a company has become a fundamental guarantee to maintain its competitive edge and an effective way to seek the current economic growth point. Thanks to its unrivalled advantages, R&D activities have played an extremely significant role in China's path to become a world power in science and technology. Currently, as most Chinese enterprises have recognized the crucial role of R&D investment and adopted aggressive innovation strategies. Their R&D investment intensity has become one of the highest in the world. The 2021 National science and technology funding investment communique released by the National Bureau of Statistics of China shows that in 2021, China's total investment in R&D funds is 2,795.63 billion yuan with a year-on-year increase of 14.6%, and the growth rate is 4.4%, higher than that of the previous year. Although there have been numerous studies in the academic community on the impact of innovation input on corporate performance, no consistent conclusions have been reached. Therefore, to facilitate related research progress, we explore the impact of R&D investment on corporate performance and further investigate the moderating effect of financing constraints.

Previous studies have shown that basic research investment can significantly improve productivity under the premise of constant R&D expenditure (Mansfield, 1980). R&D expenditures are one of the most important competitive factors that bring about technological improvements, design and implementation efficiencies, and improved products and services (Rahman and Howlader, 2022). There is intense competition within an industry, especially one based on technology, due to the growth of research and development in the market. The extremely competitive market pushes companies to seek growth opportunities and large market shares to compete with competitors through different innovation strategies and original products (Ehie and Olibe, 2010). According to some scholars, while R&D investment can improve a company's core competitiveness, it has inherent characteristics such as elevated levels of risk, strong uncertainty and prolonged R&D cycles. At the same time, R&D investment also requires the support of large amounts of capital. Funding constraints at the current stage of China's emerging capital market are relatively high due to the fact that numerous enterprises cannot afford to make frequent R&D investments and focus only on short-term corporate performance. Therefore, relatively cautious innovation strategies have been adopted to avoid uncertainties and risks encountered in R&D and innovation (Song, 2022).

In order to explore the essential factors that drive corporate performance improvement, previous studies have explored the relationship between R&D investment and corporate performance, but no consistent conclusions have been reached. With the same motivation, and to provide some inspiration for companies to make reasonable R&D investments, this study empirically tests the impact of R&D investment on corporate performance. While previous studies have investigated the impact of R&D investment on firm total factor productivity and financing constraints on corporate performance, they have not integrated the impact of R&D investment on corporate performance. Based on this study, we believe that R&D investment can further improve corporate performance by boosting total factor productivity, and that the impact of R&D investment on corporate performance is more pronounced in companies with lower financing constraints. Motivated by this, from the perspective of corporate innovation, we investigate the impact of R&D investment on corporate performance using a fixed-effects model. At the same time, the paper discusses whether there are new changes in the impact of R&D investment on corporate performance under financing constraints, in order to provide a theoretical and practical basis for corporate management to make reasonable R&D investments. The innovative points and implications of this study are mainly as follows. First, it investigates the impact of R&D investment on corporate performance and empirically tests the mechanisms by which R&D investment promotes corporate performance by influencing the total factor productivity of the business, which can enrich related research. Second, it explores whether financing constraints can play a moderating role in the impact of R&D investment on corporate performance. Third, from an internal control perspective, it also explores whether differences in internal control quality modify the impact of R&D investment on corporate performance, thus providing evidence to support companies in further promoting internal control quality.

2 Theoretical background and hypotheses development

2.1 R&D investment and corporate performance

Corporate R&D is a long process. The benefits of research and development (R&D) have been the focus of research by scholars since Schumpeter formulated the theory of innovation. Numerous studies have shown a significant positive correlation between R&D investment and corporate performance. R&D investment plays a positive role that cannot be ignored in improving product technology and quality, and meeting consumer demand (Chen and Hu, 2020). Enterprise innovation investment not only improves the core competitiveness of enterprises, but also significantly increases their productivity. At the same time, it brings new products or processes to companies that differentiate themselves, helping to increase their market share and generate excess earnings. Theoretically, by creating new products or services through R&D activities, enterprises can temporarily make monopoly profits (Lieberman and Montgomery, 2010). In fact, while strong profits from any current product may be short-lived, relatively strong corporate profits may be sustained if firms are able to launch new products, technologies or services through continuous research and development (Benlu et al., 2020). Internal R&D investment can improve the company's ability to utilize external technical knowledge and transform it into innovation, so it is conducive to improve the innovation performance of enterprises after technology merger and acquisition (Song et al., 2005). The empirical study of 272 enterprises in 35 industries conducted by Artz et al. (2010) shows that continuous introduction of new products can provide support for enterprises to achieve long-term high-level performance. According to the theory of innovation, innovation is the driving force in the development of a business, and technological research and development is the main factor in determining the uniqueness of a business. Many of the world's leading companies have particularly strong R&D capabilities. For enterprises, R&D investment can be used to improve the production technology, achieve product differentiation, broaden the market boundary, form core competitiveness, and increase the market share of enterprises, so as to gain a firm foothold in the market and promote the improvement of corporate performance (Zheng and Kun, 2021). By continuously developing new technologies and products, or revamping old ones, the production efficiency and market recognition of products can be improved, and the profitability of enterprises can be considerably enhanced, which enables enterprises to have more funds to invest in research and development, forming a virtuous circle of sustainable development. Therefore, while the impact of R&D investment on corporate performance can be volatile, overall, R&D investment can drive corporate performance improvement.

Research and development can be channeled into corporate productivity, which drives the total factor productivity of the company. According to endogenous growth theory, the only way for companies to make technological progress is to increase their total factor productivity, and R&D investment is the main vehicle for technological innovation. The increase in R&D investment can be used to introduce additional modern equipment, improve production capacity and production management methods, optimize the efficiency of resource allocation, make advanced production factors flow among different departments, and improve the total factor productivity of enterprises, thus improving corporate performance (Ren et al., 2022). Qiu and Wei (2016) found that the level of total factor productivity would be significantly improved under the high intensity of R&D investment, and R&D investment can undoubtedly improve the performance of enterprises. Therefore, we believe that R&D investment can boost the total factor productivity of enterprises and subsequently improve their performance.

In summary, we propose to research hypotheses H1 and H2:

H1. R&D investment helps improve the performance of a business.

H2. R&D investment can improve corporate performance by affecting total factor productivity.

2.2 The moderating effect of financing constraints on the relationship between R&D investment and corporate performance

Different types of R&D investments involve different risks and benefits. How to make decisions when faced with the choice of R&D investment projects and schedules is an essential financial issue for enterprises. In addition to technical feasibility, companies need to consider cost-effectiveness in terms of performance and financial controllability. At the same time, the most critical financial problem in R&D investment, namely financing constraints, has become the main factor restricting the improvement of enterprise performance (Chen and Hu, 2020). In mandate relationship, where the fundamental rights and interests of the parties are different, information asymmetries can lead to moral hazard problems. Different levels of financing constraints may lead to agent conflicts of varying degrees within the enterprise, which can then have differentiated effects on R&D performance. As Chinese enterprises commonly have financing constraints of different intensity, it is necessary to incorporate financing constraints into the analysis system of the relationship between R&D investment and corporate performance. Myers and Majluf (1984) gave the definition of financing constraint, which is essentially the difference between the internal and external financing costs of an enterprise. The financing channels for enterprises mainly include internal financing and external financing. Internal financing is mainly based on the internal surplus of an enterprise itself, while external financing mainly raises funds from financial institutions, individuals or institutional investors (Du and Li, 2022). A large body of research has consistently pointed out that financing constraints largely have a restraining effect on internal R&D investment, thereby reducing the impact of R&D on corporate performance. As an in-house R&D investment, the impact on the firm's performance is bound to be different under different funding constraints. The more constraints a company has on its R&D funds, the more focus is placed on the efficiency with which the funds can be used and the performance of the company, and the decision to spend on R&D investments will inevitably be more cautious. When financing constraints exist, enterprises will reduce the investments of R&D, thus inhibiting the improvement of innovation performance (Chen and Hu, 2020). Enterprises with high financing constraints may have R&D projects with broad development prospects, but due to risk and information asymmetry, R&D activities are stagnated, and innovation cannot be carried out (Ren et al., 2022). The development of China's capital market started late, the financial market is not perfect, the financing channels are relatively narrow, and most enterprises are faced with different degrees of financing constraints (Chen et al., 2015). Ju (2013) pointed out that the rapid increase of innovation investment of Chinese enterprises mainly benefits from internal funds, while external financing channels play a limited role, so financing constraints have a critical impact on R&D investment and performance of enterprises. Thus, in China, financing constraints will modify the impact of R&D investment on corporate performance.

In addition to inhibiting increased R&D investment, financing constraints are also detrimental to total factor productivity and corporate performance. When the financing constraints of enterprises are lower, enterprises will get more internal capital accumulation, and enhance the risk tolerance, so that enterprises can have more funds to expand reproduction, promote enterprises to actively carry out technological upgrading and other innovative activities, so as to improve the total factor productivity and performance of enterprises. With the improvement of financing constraints, the profitability of enterprises can be improved, and positive signals can be transmitted to external investors, thus attracting social funds into enterprises, and providing impetus for enterprises to expand investment reproduction, to form scale effect and improve corporate performance (Du and Li, 2022). From the perspective of improving productivity, Guo (2017) used mathematical models to explain the impact mechanism of heterogeneous R&D investment on enterprise productivity under financing constraints. His study pointed out that the imbalance in the proportion of heterogeneous R&D investment due to financing constraints had a negative impact on the productivity growth of enterprises.

In summary, we have proposed the research hypothesis H3:

H3. When financing constraints are higher, R&D investment has a smaller impact on a company's performance.

3 Research design

3.1 Sample selection and data sources

Modern accounting rules were adopted for listed Chinese companies in 2007. In late 2019, the Chinese economy began to suffer the effects of COVID-19. To avoid the impact of accounting changes and COVID-19 on the economy, the time period of our study sample was chosen to be 2007 to 2019. As only listed companies are required to provide some relevant financial statements and information, and SMEs rarely invest in R&D, we selected A-share non-financial listed companies in mainland China as our study subjects. Data for non-financial listed A-share companies in China were screened based on existing studies as follows. First, missing observations for the main study variables were removed. Second, the financial sector sample was removed. Third, companies with no R&D practices and incomplete data on major financial indicators were eliminated. Fourth, the observed values of listed companies whose shares are in an anomalous trading state, such as suspended listing, are removed. Fifth, continuous variables are reduced to control the effect of extreme values. We end up with 15, 675 sample observations. Data was collected from the CSMRA database and processed using STATA 17.0.

3.2 Variable selection

3.2.1 Dependent variable

Referring to the research of Zhang et al. (2021), we adopt return on assets (ROA) as the measurement index of enterprise performance. The higher the return on assets, the better the enterprise performance.

3.2.2 Independent variable

Referring to the research of Chen and Lu (2011), the ratio of R&D investment to operating revenue is used to measure the intensity of R&D investment (RD) of enterprises and expressed in the form of percentage. The higher the percentage, the higher the R&D investment.

3.2.3 Moderating variable

Referring to the research of Ju (2013), SA index is adopted as the measurement index of financing constraint (SA). Where,

TABLE 1 Variable definitions.

Variable	Symbol	Definition
Enterprise performance	ROC	Profit/total assets
R&D investment	RD	R&D investment/operating income
Financing constraints	SA	0.737 * SI2 SI + 0.043 0.040 x A
Total factor productivity	TFP	Measured by LP non-parametric estimation method
Enterprise growth	GRO	Revenue growth/total revenue
Free cash flow	CFO	Cash flows from operating activities/total assets
Current ratio	FRA	Current assets/current liabilities
Proportion of independent directors	EXP	Number of independent directors/Number of directors
The shareholding ratio of the largest shareholder	FIRST	Shares held by the largest shareholder/total shares
The enterprise scale	SIZE	The natural log of the total assets of the firm

SA = −0.737 × SI + 0.043 × SI2-0.040 × A, SI is the natural logarithm of the total assets of the enterprise, A is the listed years of the enterprise, and SA is negative. By taking the absolute value of SA, the larger the absolute value, the larger the financing constraint.

3.2.4 Mediating variable

We choose to measure enterprise total factor productivity (TFP) by LP non-parametric estimation method proposed in 2003.

3.2.5 Control variables

According to relevant literature (Hu and Liang, 2017; Chen and Gong, 2020; Yao et al., 2020), we selected company-level factors such as enterprise growth (GRO), free cash flow (CFO), current ratio (FRA), proportion of independent directors (EXP), shareholding ratio of the largest shareholder (FIRST) and enterprise SIZE (SIZE) as the control variables of the main regression model to eliminate the influence of heterogeneity factors on enterprise performance.

The variables selected are shown in Table 1.

3.3 Model construction

Drawing on previous studies, considering that company and year factors may affect the regression results, we construct the following Eq. 1 to test the relationship between R&D investment and corporate performance.

$$ROA_{i,t} = \alpha_0 + \alpha_1 \mathrm{RD}_{i,t} + \delta X + \varphi_i + \omega_t + \varepsilon_{i,t} \quad (1)$$

In Eq. 1, the subscript i is enterprise, t is year. The dependent variable ROA is enterprise performance, the independent variable RD is enterprise R&D investment, and X represents control variables. φ means firm fixed effects and ω means time fixed effects.

In order to test the moderating effect of financing constraints on R&D investment and enterprise performance, on the basis of Eq. 1, the multiplication term (RD*SA) of RD and SA index is added, and the dependent variable and control variables are the same as above. The specific model is as follows:

$$ROA_{i,t} = \alpha_0 + \alpha_1 RD_{i,t} + \alpha_2 RD^{*}SA_{i,t} + \delta X + \varphi_i + \omega_t + \varepsilon_{i,t} \quad (2)$$

To further empirically test the mediating effect of TFP between R&D investment and corporate performance, we establish the following mediating effect model:

$$TFP_{i,t} = \alpha_0 + \alpha_1 RD_{i,t} + \delta X + \varphi_i + \omega_t + \varepsilon_{i,t} \quad (3)$$

$$ROA_{i,t} = \alpha_0 + \beta_1 RD_{i,t} + \alpha_2 TFP_{i,t} + \delta X + \varphi_i + \omega_t + \varepsilon_{i,t} \quad (4)$$

In Eqs 3, 4, TFP is mediating variable total factor productivity. If α_1 、 β_1 and α_2 are all significant and $\beta_1 < \alpha_1$, there will be partial mediating effect. β_1 is the direct effect of R&D investment on corporate performance, and $\alpha_1{}^{*}\alpha_2$ is the mediating effect. If α_1 and α_2 were significant but β_1 was not, the direct effect was less obvious than the indirect effect.

The study will follow the following tools (see Figure 1), focusing on the methodological approach. We used the econometric software Stata 17.0 for our empirical analysis. The Stata commands used in this study include sum, asdoc, reghdfe, and bootstrap.

4 Empirical results

4.1 Descriptive statistics

Table 2 lists the descriptive statistical results for the main variables. The mean value of enterprise performance (ROA) is

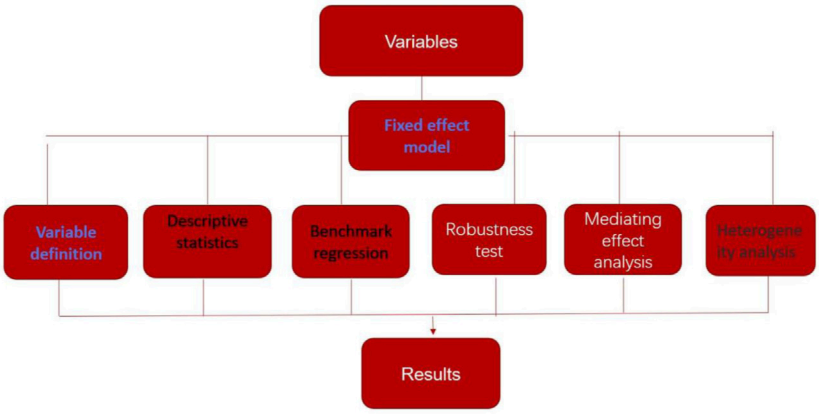

FIGURE 1
Conceptual framework.

TABLE 2 Descriptive statistics.

Variable	Obs	Mean	Std. Dev	Min	Max
ROA	15,675	0.0430	0.0500	−0.2750	0.2010
RD	15,675	0.0240	0.0210	0.0001	0.2720
CFO	15,675	0.0470	0.0620	−0.1800	0.2590
FRA	15,596	2.5720	2.2050	0.2380	16.2130
EXP	15,675	0.6290	0.0480	0.4440	1.0000
GRO	15,675	0.3210	0.7330	−0.7460	9.9710
FIRST	15,675	34.1870	13.7060	9.0900	76.0700
SIZE	15,675	21.9110	1.0690	19.0810	25.7450

0.0430, and the standard deviation is 0.0500. The average value of R&D investment (RD) is 0.0240, the maximum value is 0.2720, and the minimum value is 0.0001, indicating that the R&D investment intensity of Chinese enterprises is relatively modest on the whole, and there is still a large room for improvement.

4.2 Benchmark regression

Table 3 shows the benchmark regression results for the impact of R&D investment on corporate performance. Column (1) shows the results without adding control variables when control enterprises' fixed effects and year fixed effects, and the coefficient of RD is 0.2329, which is significant at the 1% level. Column (2) further adds control variables, and the coefficient of RD is 0.2434, which is significant at 1% level. The results show that the coefficient of RD is significantly positive in columns (1) and (2), indicating that higher R&D investment can improve the performance level of China's A-share listed companies. Therefore, hypothesis H1 has been verified.

Column (3) of Table 3 lists the results of the impact of R&D investment level on corporate performance after considering financing constraint as a moderating variable. The results show that the coefficient of the interaction term between R&D investment and financing constraint (RD*SA) is -0.1701, which is significant at 10% level. This indicates that serious financing constraints will inhibit the promoting effect of R&D investment on corporate performance. That is, financing constraints show a negative inhibitory effect on the impact of R&D investment on corporate performance. Hypothesis 3 is verified.

4.3 Robustness checks

4.3.1 Replace the dependent variable

Referring to the research of Zhu and Zhang (2013), we use the market value index Tobin Q (TBQ) to measure enterprise performance. (Tobin Q= (market value of tradable shares + number of non-tradable shares × net asset value per share + book value of liabilities)/total assets) The regression results are shown in column 1) of Table 4. The coefficient of RD is 6.0852, which is significant at the level of 1%, indicating that R&D investment can effectively promote corporate performance, in line with previous conclusions.

4.3.2 Eliminate the sample of provincial capitals.

The capital of China is the political, economic, scientific, educational, cultural and transportation center of the national first-level administrative region (generally a province). To avoid certain biases due to the special political status of provincial capitals, we excluded enterprises in provincial capitals and performed regression again. The regression results are shown

TABLE 3 Benchmark regression.

	(1)	(2)	(3)
	ROA	ROA	ROA
RD	0.2329***	0.2434***	0.8226**
	(0.0393)	(0.0389)	(0.3341)
RD*SA			−0.1701*
			(0.0974)
CFO		0.1573***	0.1571***
		(0.0065)	(0.0065)
FRA		0.0033***	0.0032***
		(0.0002)	(0.0003)
EXP		0.0022	0.0023
		(0.0111)	(0.0111)
GRO		0.0034***	0.0033***
		(0.0006)	(0.0006)
FIRST		0.0005***	0.0005***
		(0.0001)	(0.0001)
SIZE		0.0049***	0.0051***
		(0.0010)	(0.0010)
con			−0.1701*
			(0.0974)
_cons	0.0377***	−0.1049***	−0.1102***
	(0.0010)	(0.0233)	(0.0235)
Control	No	YES	YES
Firm_FE	YES	YES	YES
Year_FE	YES	YES	YES
Obs	15,465	15,381	15,381
r2_a	0.4456	0.4806	0.4807

Note: *, **, and *** denote significance at the significance level of 10%, 5%, and 1%, respectively.

in column (2) of Table 4. The coefficient of RD is 0.5198, which is significant at the 1% level. After excluding the sample of enterprises in provincial capitals, R&D investment can still significantly contribute to the improvement of business performance, which is consistent with the previous conclusions.

4.3.3 Lag the explanatory variable with the control variable by one period

Considering that there may be a time lag effect in the promotion effect of R&D investment growth on corporate performance, we regressed the independent variable and control variables in Eq. 1 after one period lag. The regression results are shown in Table 5. The LRD coefficient is 0.1881, which is significant at the 1% level. This suggests that this conclusion still holds after accounting for the possible lag effect of R&D investment on corporate performance.

5 Further analysis

5.1 Mediating effect analysis

Theoretical analysis shows that increased investment in R&D can boost business performance. Moreover, R&D investment can

TABLE 4 Robustness test 1

	(1)	(2)
	TBQ	ROA
RD	6.0852***	0.5198***
	(0.7354)	(0.0656)
CFO	1.1027***	0.1688***
	(0.1236)	(0.0093)
FRA	−0.0530***	0.0041***
	(0.0047)	(0.0004)
EXP	−0.1326	−0.0068
	(0.2103)	(0.0159)
GRO	0.0041	0.0038***
	(0.0107)	(0.0008)
FIRST	−0.0069***	0.0005***
	(0.0013)	(0.0001)
SIZE	−0.5458***	0.0097***
	(0.0191)	(0.0014)
_cons	14.2504***	−0.2118***
	(0.4415)	(0.0328)
Control	YES	YES
Firm_FE	YES	YES
Year_FE	YES	YES
Obs	15,381	7,611
r2_a	0.6033	0.4886

Note: *, **, and *** denote significance at the significance level of 10%, 5%, and 1%, respectively.

improve corporate performance by boosting total factor productivity. In the following, we analyze the mediation effect. R&D and innovation play an essential role in increasing the total factor productivity of enterprises, and can further boost their performance. According to the three-step method of the mediating effect model, we regression Eqs 1, 3, 4 respectively, to test whether the mediating effect of total factor productivity (TFP) of enterprises is significant. Columns (1) to (3) of Table 6 show the regression results of R&D investment on corporate performance, R&D investment on total factor productivity, and R&D investment and total factor productivity on corporate performance. It can be seen that R&D investment has a significantly positive effect on the total factor productivity of the enterprise, with a coefficient of 0.0433 for TFP, which is significantly positive at the 1% level, but not significant for RD when both are used to perform regression of the firm's performance. This suggests that the mediator effect is more pronounced than the direct effect.

In order to further confirm the mediating effect, the Bootstrap test was conducted on Eq. 4 in Table 6 by referring to the research of Wen and Ye (2014), and the test results are shown in Table 7 below. In Table 7, bs1 represents indirect effect and bs2 represents direct effect. It can be found that the model that passes the Bootstrap test and the mediator effect is significantly established. This suggests that R&D investment can indeed improve corporate performance by boosting total factor productivity.

5.2 whether differences in internal control quality alter the impact of R&D investment on corporate performance

Internal control is essential for enterprises to achieve strategic objectives of critical management tools. A healthy internal control system has a significant impact on R&D

TABLE 5 Robustness test 2

	(1)
	ROA
LRD	0.1881***
	(0.0495)
LCFO	0.0988***
	(0.0080)
LFRA	0.0012***
	(0.0003)
LEXP	−0.0047
	(0.0138)
LGRO	0.0038***
	(0.0007)
LFIRST	0.0004***
	(0.0001)
LSIZE	−0.0112***
	(0.0013)
_cons	0.2600***
	(0.0300)
Control	YES
Firm_FE	YES
Year_FE	YES
Obs	11,397
r2_a	0.4666

Note: *, **, and *** denote significance at the significance level of 10%, 5%, and 1%, respectively.

investment and corporate performance. On the one hand, it can improve the strain capacity of an enterprise in the presence of environmental uncertainties.; on the other hand, it can also consolidate the owner to supervise the management, positive signals to outside investors (Yan and Yang, 2022), and enhance the financing ability. By referring to the research of Zeng et al. (2022), we take the internal control index in Internal Control and Risk Management Database as the indicator to measure the quality of internal control (DIB). The higher the value of this index, the higher the quality of internal control. We then consider firms with an internal control index greater than the industry median as firms with strong internal control quality, and firms with an internal control index less than the industry median as firms with low internal control quality, and perform group regression. The regression results are shown in columns (1) and (2) of Table 8. The coefficient of influence of R&D investment on corporate performance is 0.3440, which is significant at the 1% level for companies with better quality internal controls. The coefficient of influence of R&D investment on business performance is −0.0476, but this is not significant for businesses with low internal control quality. The development of a business will be affected by the internal environment of the business. When the quality of internal control is higher, the role of R&D investment will naturally be promoted and its impact on the performance of the company will be enhanced, which is conducive to the development of the company.

5.3 Whether the difference in firm nature changes the impact of R&D investment on corporate performance

The nature of a business is an essential factor in its development. Differences in business objectives and risk control between SOEs and non-SOEs will have an impact on business activities. Therefore, it is necessary to distinguish the

TABLE 6 Mediating effect analysis.

	(1)	(2)	(3)
	ROA	TFP	ROA
RD	0.2434***	6.4807***	−0.0346
	(0.0389)	(0.2773)	(0.0410)
TFP			0.0433***
			(0.0014)
CFO	0.1573***	0.6999***	0.1340***
	(0.0065)	(0.0463)	(0.0068)
FRA	0.0033***	−0.0197***	0.0040***
	(0.0002)	(0.0018)	(0.0003)
EXP	0.0022	0.1045	−0.0021
	(0.0111)	(0.0783)	(0.0113)
GRO	0.0034***	−0.0071*	0.0038***
	(0.0006)	(0.0039)	(0.0006)
FIRST	0.0005***	0.0008*	0.0005***
	(0.0001)	(0.0005)	(0.0001)
SIZE	0.0049***	0.6483***	−0.0219***
	(0.0010)	(0.0072)	(0.0014)
_cons	−0.1049***	−5.5014***	0.1038***
	(0.0233)	(0.1664)	(0.0252)
Control	YES	YES	YES
Firm_FE	YES	YES	YES
Year_FE	YES	YES	YES
Obs	15,381	13,974	13,974
r2_a	0.4806	0.9341	0.5200

Note: *, **, and *** denote significance at the significance level of 10%, 5%, and 1%, respectively.

samples according to the nature of the property rights before conducting the study. We perform regression on the sample of state-owned enterprises and the sample of non-state-owned enterprises, respectively, and the regression results are shown in columns (3) and (4) of Table 8. It can be seen that the coefficient of influence of R&D investment on corporate performance is 0.2754 for SOEs and 0.2620 for non-SOEs, both of which are significant at the 1% level. This indicates that increased R&D investment by SOEs is more effective in improving corporate performance. Compared with non-state-owned enterprises, SOEs have an advantage in financing loans, with banks and other financial institutions more willing to lend money to powerful SOEs. Therefore, R&D investment by SOEs can promote the improvement of corporate performance.

6 Discussion of the results

In this section, we discuss the findings found in this empirical analysis. In the benchmark regression, we found that expanding R&D investment can significantly promote enterprise performance, which is consistent with some existing research results (Hall and Mairesse, 1995; Hsieh et al., 2003). Based on the findings, we ask the following questions: What are the possible explanations for the findings? We believe that the knowledge effect and positive externality brought by R&D investment can bring economic benefits to enterprises themselves, which has also been confirmed by some existing studies (Hall and Mairesse, 1995; Hsieh et al., 2003; Stam and Wennberg, 2009). For example, Stam and Wennberg (2009) found that

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TABLE 7 Bootstrap test.

	(1)
VARIABLES	y1
_bs_1	0.0916***
	(0.00610)
_bs_2	0.186***
	(0.0221)
Observations	14,165

Note: *, **, and *** denote significance at the significance level of 10%, 5%, and 1%, respectively.

TABLE 8 Heterogeneity analysis.

	(1)	(2)	(3)	(4)
	ROA	ROA	ROA	ROA
RD	0.3440***	−0.0476	0.2754***	0.2620***
	(0.0416)	(0.0805)	(0.0650)	(0.0477)
CFO	0.1161***	0.1950***	0.1565***	0.1573***
	(0.0071)	(0.0133)	(0.0108)	(0.0080)
FRA	0.0014***	0.0053***	0.0052***	0.0027***
	(0.0003)	(0.0006)	(0.0007)	(0.0003)
EXP	0.0030	0.0186	0.0365**	−0.0084
	(0.0123)	(0.0215)	(0.0175)	(0.0140)
GRO	0.0018***	0.0047***	0.0013	0.0042***
	(0.0006)	(0.0011)	(0.0008)	(0.0007)
FIRST	0.0003***	0.0007***	0.0000	0.0006***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)
SIZE	0.0011	0.0071***	0.0035*	0.0077***
	(0.0011)	(0.0020)	(0.0018)	(0.0012)
_cons	0.0025	−0.1862***	−0.0926**	−0.1565***
	(0.0265)	(0.0456)	(0.0419)	(0.0286)
Control	YES	YES	YES	YES
Firm_FE	YES	YES	YES	YES
Year_FE	YES	YES	YES	YES
Obs	6,714	6,727	4,409	10,900
r2_a	0.6332	0.3503	0.5286	0.4658

Note: *, **, and *** denote significance at the significance level of 10%, 5%, and 1%, respectively.

research and development made it possible to utilize external knowledge, thus promoting the development of enterprises.

To show more concrete knowledge effects and positive externality brought by R&D investment, we then perform a mediation effect analysis. The results show that R&D

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investment boosts the total factor productivity of enterprises, which then improves their performance. The finding that R&D investment promotes TFP improvement is consistent with numerous existing literature (Wang and Li, 2017; Liu and Lin, 2021). In addition, when the resulting total factor productivity increases, the company's performance also improves.

In our analysis of the impact of financing constraints on the relationship between R&D investment and corporate performance, we found that the lower the financing constraints, the more R&D investment can be used to boost corporate performance. We believe that financing constraints are constraining companies in every way. When financing constraints are serious, enterprises will have difficulties in R&D investment and thus hinder the improvement of total factor productivity, which is consistent with the conclusions of existing literature (Ren et al., 2022; Zhao et al., 2015).

In the heterogeneity analysis, we explore whether the difference between the level of internal control and the nature of the firm changes the impact of R&D investment on corporate performance. The results show that R&D investment has a greater impact on corporate performance when the level of internal control is higher and when the company is state-owned. According to existing literature, a higher level of internal control of enterprises represents better corporate governance and is conducive to increasing enterprise value (Tian and Chen, 2015). However, companies with defective internal control will increase the risk of falling stock market price, and face higher audit fees and systemic risks, which will affect corporate performance (Hogan and Wilkins, 2008; Dhaliwal et al., 2011). These ideas are consistent with the results of this study. For state-owned enterprises, their special status will bring numerous conveniences, such as easier access to loans, and further expand the impact of R&D investment on corporate performance, which is consistent with some existing research conclusions (Deng and Sun, 2014; Ali et al., 2019).

7 Conclusion

In the context of China's economic transition, the development of enterprises is often considerably influenced by innovation factors such as R&D investment. The orderly development of R&D activities can help enterprises improve their technical level, continuously introduce new products with greater market competitiveness, or improve their technological processes, enabling them to reduce costs and improve production efficiency and performance. In fact, this study will shed some light on the formulation of rational R&D investments and lay the foundation for subsequent related studies.

Using Chinese A-share listed companies from 2007 to 2019 as a sample for the analysis, we empirically study the impact of R&D investment on corporate performance and the moderating effect of financing constraints. Then we draw the following conclusions. First, the higher the investment in research and development, the better the improvement in corporate performance. This conclusion still holds after robustness checks. In addition, financing constraints will significantly alter the impact of R&D investment on corporate performance. The lighter the financing constraints, the more additional R&D investment can be used to boost corporate performance. Second, according to the mediation effect analysis, R&D investment can modify corporate performance by affecting the firm's total factor productivity. Third, R&D investment by companies with higher internal control quality are more conducive to improving their performance than those with lower internal control quality. Fourth, R&D investment by SOEs can significantly boost the performance of companies compared to non-SOEs.

As an essential means of corporate management, internal control can ensure better business activities, reduce information asymmetry, and enhance corporate trust. Therefore, improving the level of internal control of enterprises will promote better conversion of R&D investment into high-yield products and improve corporate performance. This view is supported by some literature (Wang and Li, 2015; Wang and Jiang, 2022).

8 Policy recommendations

What policy recommendations might emerge from this study? The motivation for this study is not only to explore the impact of R&D investment on corporate performance, but also to focus on the impact of financing constraints in this context. Based on the findings of the study, We propose the following. First enterprises should increase R&D investment, spend money where it counts the most, and strive for breakthroughs in core and key technologies. Second, we should strengthen the construction of government services, optimize the business environment, standardize information disclosure (alleviate the problem of information asymmetry), better meet the needs of investors and creditors, so as to reduce external financing costs and improve the financing constraints faced by enterprises. In addition, the government should increase fiscal and tax support, increase credit support, optimize financing services, and improve the financial availability of private enterprises (especially SMEs). Third, the enterprise should proceed from the characteristics of the industry, be risk-oriented, take into account the principle of cost effectiveness, strengthen the internal supervision, control and governance of the enterprise, and pay more attention to the supervision environment, critical control points, information transmission process and other essential parts.

And even though China has focused for years on solving the difficult and costly financing problem for small and medium-sized enterprises, it has not fundamentally solved the problem. In

China, the venture capital threshold is relatively steep and listing is more difficult. The vast majority of SME financing still relies on creditor claims and bank loans. Bank lending, however, invariably favors strong public companies. Therefore, the shortage of loan supply for SMEs is the root cause of their financing difficulties. We believe that we should pay attention to solving the problem of information asymmetry of enterprises, improve the enthusiasm of banks in lending to tiny and medium-sized enterprises, vigorously develop and standardize the complementary role of non-bank financial institutions in the field of lending to tiny and medium-sized enterprises, give play to the "catfish" effect of non-bank financial institutions, and create competition pattern and market pressure for banks. Finally, this research topic can open up channels for policy discussions among industry, government and researchers to promote effective cultivation of corporate innovation capacity, ease financing constraints and strengthen internal controls.

9 Study recommendations and limitations

Still, the research is not without limitations. This study focuses only on the Chinese case and lacks empirical analysis of other countries. The specific coefficient of impact of R&D investment on corporate performance measured in this paper is 0.2434. However, there are a large number of listed companies in China and the situation varies from company to company, so it is difficult for companies to make specific R&D investment plans based on this figure. This study does not consider the case of unlisted Chinese companies due to difficulties in obtaining data and other issues, and is therefore of minor reference for SMEs. This study was not able to measure the specific impact of financing constraints on the relationship between R&D investment and corporate performance. Moreover, this study does not provide a more specific empirical analysis of the way R&D investment affects corporate performance. If more practical experience could be provided on the impact of R&D investment on corporate performance, it would provide additional support for the development of R&D theory and a greater understanding of the positive externality of R&D.

Advance research should consider additional countries and construct different metrics to measure R&D spending through SMEs. Researchers should construct a model that can accurately measure the impact of financing constraints on the relationship between R&D investment and corporate performance, and further explore ways to mitigate financing constraints. In addition, researchers should also consider the long-term impact of R&D investment on corporate performance.

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 authors.

Author contributions

XW: Conceptualization, methodology, formal analysis, funding acquisition and writing—original draft. MF: Methodology, writing—original draft, resources, supervision, software, writing—review and editing. YF: Software, validation, investigation, data curation, and writing—original draft. YL: Proofreading, data analysis and conclusion modification. XT: Proofreading and literature review.

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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Do state-owned participation shareholders improve the environmental governance level of private enterprises? Evidence from Chinese listed firms

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In recent years, whether the mixed-ownership reform system of introducing state-owned participation shareholders into private enterprises helps to improve the environmental governance of private enterprises has been a matter of much attention and discussion. Based on data from 2007 to 2019 for Chinese A-share privately listed companies, this paper examines how the state-owned participation shareholders affect the environmental governance level of private enterprises. The results show that state-owned participating shareholder participation can improve the environmental governance level of private enterprises, and this phenomenon is more significant among industrial enterprises and enterprises in regions with a higher degree of marketization. Furthermore, there is a substitution effect between the state-owned participation shareholders, the executive team's participation in politics, and the Party organization establishment in improving the environmental governance level of private enterprises, and the state-owned participation shareholders play a relatively larger role. In addition, the supervision effect is better when state-owned participation shareholders are from the local area and have a higher level of participation.

KEYWORDS

state-owned participation shareholders, mixed-ownership reform, private enterprises, environmental governance level, industrial enterprises, marketization degree

1 Introduction

Environmental governance is an important way to promote the construction of ecological civilization. In 2022, China's "Government Work Report" clearly states that the focus should be on "strengthening pollution prevention and ecological construction and continuously improving environmental quality", emphasizing that the government and enterprises should continue to strengthen the governance of the ecological environment and continuously promote the construction of ecological civilization. However, under the high pressure of environmental protection, the problem of environmental pollution still exists in China (Luo and Lai, 2016). According to the China State of the Environment Bulletin, although the quality of the ecological environment has generally improved, the construction of ecological civilization is still facing the grim situation of tightening resource constraints, serious environmental pollution, and ecosystem degradation. The current environmental pollution problem in China is mainly manifested by the lack of enterprise awareness and action on environmental governance and the generally low investment in environmental governance (Li et al., 2020). Although 80% of environmental pollution in China comes from enterprises, more than 70% of the investment in environmental governance comes from the government (Feng and Sun, 2020). As the main source of environmental pollution, enterprises are supposed to be an important subject of environmental governance, and the improvement of environmental quality relies heavily on the enthusiasm for enterprises' environmental governance. However, the negative externalities of the environment make enterprises pursuing economic benefits lack the motivation of environmental governance (Orsato, 2006; Tang et al., 2013). Especially for private enterprises, their business activities are less subject to government intervention than state-owned enterprises, and they are more sensitive to the cost of environmental governance, thus taking less responsibility for environmental protection and causing more serious environmental pollution problems. It has been shown that government-led administrative means are the main factor driving the environmental governance of private enterprises (Gao and Zheng, 2017; Xie et al., 2017; Zhou and Shen, 2019; Liu et al., 2020). While the measures taken by private enterprises in environmental governance due to the government's administrative measures are still essentially a "reactive" response to environmental problems. Therefore, to solve the long-term environmental pollution problems of private enterprises, the most fundamental thing is to strengthen the supervision and governance of enterprises, and to increase their motivation to carry out environmental governance, so that they can participate in environmental governance "actively".

State-owned equity participation in private enterprises is a crucial method to strengthen the supervision and management of enterprises (Li et al., 2017). Since the third plenary session of the 18th CPC central committee proposed "actively developing mixed-ownership economy", mixed-ownership reform has rapidly become a hot topic in all sectors of society. The main purpose of the mixed ownership reform is to achieve common development and effective checks and balances among different ownership capital, and the form of reform includes not only the participation of non-state capital in state-owned enterprises but also the participation of state-owned capital in non-state-owned enterprises. Chinese State Council issued the document "Opinions of the State Council on the Development of Mixed Ownership Economy in State-owned Enterprises" in 2015, which points out that "encouraging state-owned capital to participate in non-state-owned enterprises in various ways and actively develop a mixed-ownership economy". This provides new guidance for the reform of private enterprises in the new era of socialism with Chinese characteristics and proposes a new way of supervising and managing enterprises. With the continuous reform and improvement of the mixed-ownership system, the "complementarity" of heterogeneous shareholders enables private enterprises to take advantage of different ownership capital (Wei and Song, 2020; Li et al., 2021). Numerous studies have found that state-owned participation shareholders have a dual economic and supervisory role in the enterprise. On the one hand, the introduction of state-owned participation shareholders makes private enterprises form a political association with the government (Deng and Wang, 2020), which brings more economic resources and development opportunities for private enterprises (Khwaja and Mian, 2005; Yu et al., 2017). On the other hand, the equity check and balance structure formed by the state-owned participation shareholders and the private controlling shareholders can effectively supervise the controlling shareholders and management, which improves the efficiency of private enterprises' investment and financing (Li et al., 2021). More importantly, because of the social responsibility of state-owned participation shareholders, they tend to pay more attention to environmental protection than private enterprises (Tang et al., 2013). So, when state-owned equity participates in private enterprises, can it exercise the right to supervise environmental protection on behalf of the state and government, implement the environmental protection responsibilities of private enterprises, and hence promote private enterprises to actively engage in environmental governance? In the context of the current mixed-system reform, it is of great theoretical and practical significance to answer this question.

Environmental governance for enterprises is most notably reflected in environmental investment (Hu et al., 2017). The State Environmental Protection Administration defines environmental investment as the funds used by enterprises to prevent pollution and protect and improve the ecological environment, and (Patten, 2005) states that corporate environmental investment is a relatively accurate and representative objective indicator of the environmental governance level. Based on this, we use Chinese A-share listed private enterprises from 2007 to 2019 as a research sample and employ corporate environmental investment as a proxy variable for the environmental governance level, to examine the impact of state-owned participation shareholders on the environmental governance level of private enterprises. The empirical result shows that state-owned participation shareholders have significantly promoted the environmental governance level of private enterprises, and the promotion effect is more significant among industrial enterprises and enterprises in regions with a higher degree of marketization. Further study finds that there is a substitution effect between state-owned participation shareholders, executive team's participation in politics, and party organization establishment on the environmental governance level of private enterprises, and the state-owned participation shareholders play a relatively larger role; when state-owned participation shareholders are from the local area and have a higher degree of participation, they can play a better supervision effect.

In contrast with the existing literature, our study makes several contributions. First, we expand the research in the area of economic consequences for state-owned participation shareholders from the perspective of corporate environmental governance. Studies on state-owned participation shareholders have mainly focused on enterprise investment and financing (Li et al., 2021), cash flow level (Wei and Song, 2020), TFP(Yin et al., 2018), enterprise transparency (Zhao and Mao, 2022), enterprise innovation (Luo and Qin, 2019) and performance (Yu et al., 2017)aspects. For example, Li et al. (2021) found that state-owned shares within private firms, which act as political affiliations, help them to obtain more bank loans and longer loan terms. Luo and Qin (2019) noted that state-owned equity participation significantly contributed to the innovation investment of family private enterprises. Yu et al. (2017) found that state-owned equity participation in private enterprises acted as a reputational guarantee at the institutional level and helped private enterprises to access more economic resources and development space, thus improving the financial performance. These studies have mainly focused on the impact of the equity structure of state-owned shareholders' checks and balances on firm-level economic performance in private enterprises, and there is a lack of exploration in terms of enterprise environmental governance. In contrast to existing studies, we explore the mechanism of the impact of state-owned participation shareholders on enterprise environmental governance from the purpose and supervision effect of state-owned equity participation in private enterprises, combining the two influential pathways of exercising voting rights and supervision management, which can be a useful supplement to the existing studies.

Second, we enrich the literature on enterprise environmental governance from the perspective of shareholder heterogeneity. The existing literature mainly focuses on administrative instruments of government departments (Xie et al., 2017; Zhou and Shen, 2019; Liu et al., 2020), executive characteristics (Hu et al., 2017; Schaltenbrand et al., 2018; Xu and Yan, 2020) and other perspectives to explore the factors driving environmental governance, studies involving the shareholder heterogeneity affecting environmental governance have mainly focused on two aspects: institutional shareholders and foreign investors. For example, (Zhao et al., 2019) and (Dyck et al., 2019) found that field visits by green institutional investors can motivate companies to actively take responsibility for environmental governance and thus improve environmental governance performance. Gulzar et al. (2019) pointed out that foreign shareholders can improve companies by improving environmental governance techniques and actively participating in enterprise governance to enhance the environmental governance level. However, so far, there are few discussions combining the perspective of state-owned participation shareholders. Compared to external supervision, state-owned participation shareholders have a broader scope and stronger enforcement power and usually have more say in the supervision of enterprise environmental governance. Therefore, we explore the driving mechanism of enterprise environmental governance based on the research perspective of state-owned participation shareholders, further expanding the research related to the relationship between shareholder heterogeneity and environmental governance.

Third, our analysis of state-owned participation shareholders and the enterprise environmental governance level helps government departments to develop a comprehensive understanding of the relationship between mixed-ownership reform and corporate environmental governance. The importance of environmental governance at the national strategic level and the leading role of mixed-ownership reform as a top-level design for China to promote subsequent economic reforms, make the issue of environmental governance of private enterprises in mixed-ownership reform particularly important. In this context, discussing the impact of state-owned participation shareholders on the enterprise environmental governance helps government departments and state-owned participation shareholders to adjust the target and proportion of participation in a more targeted manner, and implement differentiated participation for enterprises in different industries and regions to improve their environmental governance level, provides an empirical basis for private enterprises to further deepen the mixed-ownership reform at this stage. It is significant to achieve the policy goal of ecological civilization construction.

2 Hypothesis development

Under governmental pressure to protect the environment, enterprise environmental governance practices often act on enterprise environmental investment behavior decisions through effective internal supervision mechanisms. Therefore, effective internal supervision is an important driver of enterprise environmental governance. As a participant of the company, the state-owned participation shareholders need to fulfill the supervisory and management authority of the funders while achieving the goal of preserving and increasing the value of state-owned capital (Li et al., 2021). Specifically, state-owned participation shareholders can exert supervisory effects to promote the environmental governance of private enterprises (Li et al., 2017).

First, state-owned participation shareholders can exercise their voting rights to express their views on basic business management decisions of the company, etc., and exert a supervisory effect, thus improving the enterprise's environmental governance level. Enterprise environmental governance is a public affairs activity with high investment costs, long lead time, and high risks, which makes private enterprises pursuing economic interests less motivated to participate in environmental governance. State-owned participation shareholders, as social responsibility bearers, not only consider the economic benefits of the enterprise but also expect the enterprise to have good performance in environmental and other social responsibilities. When state-owned equity participates in private enterprises, they may take relevant measures to influence the business management decisions to a certain extent (Yu et al., 2017), and improve the enthusiasm for enterprise environmental governance. On the one hand, state-owned participation shareholders have more advanced social responsibility undertaking concepts and practical experience and can integrate their social responsibility preferences in the supervision process of enterprise decision-making, and guide enterprises to make more decisions that are conducive to environmental responsibility undertaking and environmental governance participation through the exercise of voting rights. On the other hand, the increase in enterprise environmental governance participation brought about by the effective guidance of state-owned participation shareholders on enterprise management decisions can further improve the social reputation of the company and improve its sustainable development (Deng and Wang, 2020). The resulting competitive advantage will be able to gain the recognition of other small and medium-sized shareholders and other stakeholders in private enterprises, increasing the possibility of their active participation in environmental governance, which in turn can improve the overall environmental governance level of the enterprise.

Second, state-owned participation shareholders can effectively curb the self-interest and short-sightedness of managers, reduce the opportunity for managers to misappropriate company resources, and exert a supervisory effect on them, thereby improving the environmental governance level of the enterprise. According to agency theory, in the absence of effective supervision, managers may act shortsightedly out of their interests, choosing the economic projects that are most beneficial to themselves at the expense of shareholders and abandoning environmental governance projects with high investment and low returns (Carl et al., 2012). At the same time, managers are likely to use information asymmetry to appropriate company resources and reduce the investment funds available for enterprise environmental governance. State-owned participation shareholders have a wide range of supervision and strong enforcement power and can implement effective internal supervision of managers (Zhong et al., 2020). On the one hand, state-owned participation shareholders exert pressure on managers by submitting proposals to the general meeting, negotiating, and replacing management members, and transferring environmental responsibilities to the managers of their participating private enterprises at each level, thus effectively curbing the self-interest and short-sightedness of managers and making them pay more attention to the long-term interests of private enterprises (Bradshaw et al., 2019) and undertake environmental governance projects, thus improving the enterprises' environmental governance level. On the other hand, the state-owned participation shareholders increase the resources of private enterprises to conduct environmental governance by investigating and punishing managers' misappropriation of interests in internal control management, thus reducing the opportunity for managers to misappropriate the company's resources. Based on the above analysis, Hypothesis 1 is proposed.

Hypothesis 1: Ceteris paribus, state-owned participation shareholders can improve the environmental governance level of private enterprises.

The role of state-owned participation shareholders in improving the environmental governance level of private enterprises is influenced by industry heterogeneity. Different industries generally face different market environments and government regulations, resulting in large differences in the level of market competition and financial performance between industries, which affects the environmental responsibility and environmental governance level of enterprises (Tang et al., 2013). Given that industrial enterprises are the main source of current environmental pollution in China, they face stricter environmental and industry regulations and greater pressure to reduce emissions than enterprises in other industries and are also closely watched by the government, society, and the public (Du and Li, 2020). According to the theory of environmental fiduciary responsibility, the industrial sector should perform more responsibilities of environmental protection and strengthen environmental responsibility. Therefore, when state-owned participation shareholders are introduced to industrial private enterprises, the state-owned participation shareholders urge the enterprises to give increasing weight to environmental pollution problems by exercising their supervisory power, and prompt them to invest more environmental protection funds for the purchase of environmental protection facilities, the improvement of environmental protection technologies and systems, and the treatment of pollution emissions, to increase the treatment of industrial pollution and improve the efficiency of pollution treatment. Based on the above analysis, Hypothesis 2 is proposed.

Hypothesis 2: Ceteris paribus, the positive effect of state-owned participation shareholders on the environmental governance level of private enterprises is more significant in industrial enterprises.

The role of state-owned participation shareholders in improving the environmental governance level of private enterprises is influenced by the degree of regional marketization. Uneven economic development across regions in China has led to large differences in the degree of marketization among regions. When located in regions with a lower degree of marketization, where there is more government intervention and a relatively lagging economic development and governance environment, information asymmetries may exacerbate agency conflicts and may also face higher government agency costs resulting from government intervention (John et al., 2011). In this environment, private enterprises will be more likely to choose projects with greater investment benefits rather than environmental governance to achieve local economic development goals. Conversely, when the degree of regional marketization is relatively high, the external economic and legal environment is better, there is less government intervention, and the local government pays more attention to the protection of the ecological environment (Zhang et al., 2022). At this time, the introduction of state-owned participation shareholders by private enterprises will not only improve the governance structure and supervision mechanism of the enterprises but also their business objectives and development strategies will be improved with the entry of state-owned participation shareholders with environmental protection obligations, prompting them to make more environmental investments. Therefore, compared to regions with a lower degree of marketization, the introduction of state-owned equity in private enterprises in regions with a higher degree of marketization can better play a supervisory effect, promote private enterprises to make environmental investments, and improve environmental governance levels. Based on the above analysis, Hypothesis 3 is proposed.

Hypothesis 3: Ceteris paribus, the positive effect of state-owned participation shareholders on the environmental governance level of private enterprises is more significant in regions with higher levels of marketization.

3 Research design

3.1 Sample selection and data sources

We take 2007–2019 Chinese A-share listed private companies as the initial sample, considering that companies implement new accounting standards from 2007, to avoid research errors caused by changes in accounting standards. On this basis, the initial sample is screened as follows: 1) excluding samples with missing data on relevant variables; 2) excluding samples of ST, *ST, and PT. According to the Company Law and the Securities Law, the Stock Exchange will impose "Special Treatment" (ST) on the trading of shares of listed companies with abnormal financial and other financial conditions for two consecutive years. When a listed company has losses for three consecutive years, it will become a delisting risk warning "*ST", its shares will be suspended, and the stock exchange will implement "Particular Transfer" (PT) for such suspended stocks. Such companies have abnormal financial and operational conditions, and their enterprise environmental governance levels are not representative; 3) excluding samples of financial companies, because the financial industry is subject to special regulation and accounting data have different meanings; 4) excluding samples with changes like enterprise ownership during the sample period, to exclude the impact of frequent changes in the nature of enterprise ownership on the study findings during the sample period; 5) referring to the method of (Li et al., 2021), the scope of state-owned participation shareholders is defined as the State-owned Assets Supervision and Administration Commission and other relevant government departments, state-owned enterprises, four major state-owned asset management companies, etc., excluding financial shareholders such as social security funds and investment accounts, and finally obtaining 10,436 observations. The state-owned equity data is collected from the top ten shareholders' "ownership property" in the company's annual report and websites such as QiChacha Enterprise Search, and the financial data is obtained from the CSMAR database. In addition, to mitigate the effect of extreme values on the results, the continuous variables are Winsorized at the 1% and 99% quartiles.

3.2 Variable selection

Independent variable: State-owned participation shareholders (State). Drawing on the study of Yu et al. (2017), we use two measures: 1) The shareholding of state-owned participation shareholders (*State1*), which takes the value of 1 if the top ten shareholders of private enterprises contain state-owned participation shareholders and 0 otherwise; 2) The shareholding ratio of state-owned participation shareholders (*State2*), the sum of the shareholding proportion of state-owned participation shareholders in the top ten shareholders of private enterprises.

Dependent variable: environmental governance level (*EI*). Drawing on Tang et al. (2013), environmental investment, which is the ratio of enterprise environmental protection investment to total enterprise assets at the end of the year, is used to measure the environmental governance level of enterprises. In particular, data on environmental investment are obtained from the increase in capital expenditures related to environmental protection disclosed by listed companies in the construction-in-progress account in the notes to their annual reports. In addition, to improve the readability of the regression coefficients, the test treats the environmental governance level variable by multiplying it by 100 according to the basis of the values taken.

Regulated variables:

1) The industry in which the enterprise is located (*Industr*), a dummy variable that is assigned a value of 1 if the enterprise is located in an industrial enterprise and 0 otherwise, according to the document "Industry Classification of National Economy" issued by the SEC in 2012.
2) The degree of marketization (*Market*), using the marketization index value of each province (city, district) constructed by Fan and Wang (2018). The higher the index, the higher the degree of marketization.

The choice of control variables is based on three main considerations: First, at the level of firm characteristics, environmental investment is an investment behavior of firms and is necessarily influenced by firm fundamentals, so with reference to previous literature (Porter and Linde, 1995; Tang et al., 2013; Hu et al., 2017; Feng and Sun, 2020), we control for variables such as firm age (*Age*), firm size (*Size*), firm growth (*Growth*), profitability (*ROA*), financial leverage (*Lev*), capital expenditure (*Capx*) and operating cash flow (*Cfo*). Second, at the level of internal corporate governance, factors such as shareholding structure, board structure, and executive characteristics can indirectly affect the environmental governance level by influencing firms' investment decisions (Carl et al., 2012; Tao and Liu, 2013; Schaltenbrand et al., 2018; Dyck et al., 2019; Zhao and Mao, 2022), so we also control for the proportion of institutional shareholding (*INSR*), board size (*Board*), the proportion of independent directors (*Indp*), and dual employment (*Dual*) variables. Third, at the level of the firm's external environment, according to previous literature (Orsato, 2006; Gao and Zheng, 2017; Zhou and Shen, 2019), the degree of market competition of the enterprise and the strength of government environmental regulation also have an impact on the environmental governance of a firm at a certain period, so we also control for the variables of industry concentration (*HHI*) and the environmental regulation effects (*ER*). In addition, we control for industry and year in the model to minimize the impact of industry characteristics and time trends on enterprise environmental governance. The specific variables are defined as shown in Table 1.

3.3 Empirical model

To test the effect of state-owned participation shareholders on the environmental governance level of private enterprises, we construct a regression model (1).

$$\begin{aligned} EI_{i,t} = {} & \alpha_0 + \alpha_1\, State_{i,t} + \alpha_2\, Age_{i,t} + \alpha_3\, Size_{i,t} + \alpha_4\, Growth_{i,t} \\ & + \alpha_5\, ROA_{i,t} + \alpha_6\, Lev_{i,t} + \alpha_7\, Capx_{i,t} + \alpha_8\, Cfo_{i,t} + \alpha_9\, INSR_{i,t} \\ & + \alpha_{10}\, Board_{i,t} + \alpha_{11}\, Indp_{i,t} + \alpha_{12}\, Dual_{i,t} + \alpha_{13}\, HHI_{i,t} \\ & + \alpha_{14}\, ER_{i,t} + \varepsilon_{i,t} \end{aligned} \tag{1}$$

In model (1), the subscript *i* denotes different firms in the sample and *t* denotes different years, and we are mainly concerned with the direction and significance of the estimated coefficient α_1 of $State_{i,t}$. According to the previous analysis, if the hypothesis holds, α_1 will be significantly larger than zero. Since we used panel data, to determine whether the regression model uses a fixed-effects model or a random-effects model, we first conducted a Hausman-test, and the test result *p*-value was .0000, so the original hypothesis was rejected and the fixed-effects model was used. To test Hypothese 2 and 3, we group the entire sample according to the industry heterogeneity of private enterprises, and the median value of the marketability index, respectively, and compares the differences in the role of state-owned participation shareholders in improving the environmental governance level of private enterprises.

4 Empirical results and analysis

4.1 Descriptive statistical analysis

The descriptive statistics of the main variables are shown in Table 2. As can be seen from Table 2, the total sample size is 10,436, the mean value of the environmental governance level (*EI*) is .118 and the median value is 0, indicating that the amount of enterprise environmental management investment is about .12% of total assets and the sample as a whole has a right-skewed distribution. The maximum value is 4.058 and the minimum value is 0, indicating that there is a large difference in the environmental governance level between different private enterprises. At the same time, only 17% of all the companies in the sample carried out environmental governance, and the motivation for environmental governance of privately listed companies is low. Among the independent variables, the mean value of the shareholding of state-owned participation shareholders (*State1*) is .409, i.e. 40.9% of private enterprises have state-owned participation shareholders, indicating that the introduction of state-owned participation shareholders in private enterprises is a relatively common phenomenon. The mean value of the shareholding ratio of state-owned participation shareholders (*State2*) is .018 and the maximum value is .218, indicating that the shareholding ratio of state-owned

TABLE 1 Meaning and description of variables.

	Variable symbol	Variable name	Meaning and calculation method
Dependent variables	*EI*	Environmental governance level	Environmental investment/total assets
Independent variables	*State1*	The shareholding of state-owned participation shareholders	Existence of state participating shareholders among the top ten shareholders of the company = 1, otherwise = 0
	State2	The shareholding ratio of state-owned participation shareholders	The total shareholding ratio of all participating shareholders in the top ten shareholders of the company
Regulating variables	*Industr*	Industry heterogeneity	Industrial enterprises = 1, non-industrial = 0
	Market	Level of marketization	Marketization index values by province (city, region) constructed by fan and wang
Control variables (*Control*)	*Age*	Firm age	Ln (year of observation—a year of establishment +1)
	Size	Firm size	Ln (total assets at end of period)
	Growth	Firm growth	(Current year amount of operating income—Prior year amount of operating income)/(Prior year amount of operating income)
	ROA	Profitability	Net profit/total asset balance
	Lev	Financial leverage	Gearing ratio = liabilities/assets
	Capx	Capital expenditure	(Cash paid for the acquisition of fixed assets, intangible assets, and other long-term assets—net cash recovered from the disposal of fixed assets, intangible assets, and other long-term assets)/total assets
	Cfo	Operating cash flow	Net cash flows from operating activities/total assets
	INSR	Percentage of institutional holdings	Total institutional shareholding among the company's shareholders
	Board	Board size	Ln (number of board members)
	Indp	The proportion of independent directors	Number of independent directors/number of board of directors
	Dual	Dual employment	The chairman and the general manager take 1 when combined, otherwise 0
	HHI	Industry concentration	Herfindahl—Hirschmann index
	ER	Environmental regulatory efforts	The environmental regulation composite index
	Industry	Industry fixed effects	Industry dummy variables, manufacturing by the explicit breakdown
	Year	Time fixed effect	Annual dummy variables

participation shareholders varies considerably across private enterprises. Among the control variables, the mean and median of indicators such as enterprise age (*Age*), enterprise size (*Size*), and enterprise growth (*Growth*) are the same, indicating that the variables generally conform to a normal distribution; the median and minimum value of the proportion of independent directors (*Indp*) is .333, the mean is .376, and the standard deviation is .052. It indicates that the number of independent directors in the sample accounts for 37.6% of the board of directors, and the differences between companies are small. According to the Guidance on Establishing Independent Director System in Listed Companies issued by CSRC, the board of directors of listed companies should include at least one-third of independent directors, which indicates that most companies comply with the regulation.

4.2 Univariate mean test

To analyze how state-owned participation shareholders affect the enterprise environmental governance level, we grouped private enterprises according to the shareholding of state-owned participation shareholders and conducted t-tests on the main dependent variables, and the results are shown in Table 3. Where *State1 = 0* indicates the sample of companies without the shareholding of state-owned participation shareholders and *State1 = 1* indicates the sample of companies with the shareholding of state-owned participation shareholders. The mean value of environmental governance level is .152 in the sample with state-owned participation shareholders, and .095 in the sample without state-owned participation shareholders, the *t*-test values of both are significant at the 1% level. This indicates that there is a significant difference between the two, with a higher average level of environmental governance in the sample of companies with the existence of state-owned participation shareholders. The above results indicate that the existence of state-owned participation shareholders can improve the environmental governance level of private enterprises, which tentatively supports Hypothesis 1.

4.3 Regression results and analysis

4.3.1 Main regression results

To examine the effect of state-owned participation shareholders on the environmental governance level of private enterprises, we

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TABLE 2 Descriptive statistics.

Variable	N	Mean	Std. Dev	Median	Min	Max
EI	10,436	.118	.543	.000	.000	4.058
State1	10,436	.409	.492	.000	.000	1.000
State2	10,436	.018	.038	.000	.000	.218
Industr	10,436	.811	.392	1.000	.000	1.000
Market	10,436	8.386	1.546	9.109	3.900	10.000
Age	10,436	2.645	.407	2.708	1.386	3.367
Size	10,436	21.778	.976	21.671	20.046	24.686
Growth	10,436	.192	.321	.143	−.430	1.705
ROA	10,436	.049	.053	.046	−.197	.197
Lev	10,436	.368	.181	.359	.047	.791
Capx	10,436	.059	.050	.046	−.010	.238
Cfo	10,436	−.143	.257	−.107	−.938	.476
INSR	10,436	35.230	25.077	33.301	.087	87.121
Board	10,436	2.100	.180	2.197	1.609	2.485
Indp	10,436	.376	.052	.333	.333	.571
Dual	10,436	.355	.478	.000	.000	1.000
HHI	10,436	.004	.006	.002	.001	.040
ER	10,436	.854	.607	.798	.000	2.179

TABLE 3 T-test for the mean of the variables grouped.

	State1 = 0	*State1* = 1	Difference value	T-test value
EI	.095	.152	−.057	−4.978***
N	6,165	4,271		

***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively.

regress the full sample according to model (1), and Table 4 provides the regression results of the relationship between state-owned participation shareholders and the environmental governance level of private enterprises. Among them, no control variables are included in columns 1) and 3), and only industry-level and time-level fixed effects are controlled for; in columns 2) and 4), to examine the robustness of the regression results, control variables, and industry-level and time-level fixed effects are further included. The results in columns 2) and 4) realize that the coefficient estimates of .043 for the shareholding of state-owned participation shareholders *(State1*) and .662 for the shareholding ratio of state-owned participation shareholders (*State2*) are significant at the 1% level and are not significantly different from the coefficient estimates in columns 1) and 3). The above regression results indicate that the state-owned equity participation in private enterprises has played its due supervisory effect and prompted private enterprises to increase their environmental investment. In terms of economic significance, private enterprises with the existence of state-owned participation shareholders have a higher environmental governance level compared to private enterprises without state-owned equity participation; the environmental governance level of private enterprises increases by .662% on average when the shareholding of state-owned participation shareholders increases by one unit. Overall, the results in Table 4 are consistent with the theoretical derivation and support Hypothesis 1.

4.3.2 Group test results

1) Group tests of the enterprise's industry heterogeneity. Table 5 reports the effect of the industry heterogeneity of private enterprises on the relationship between the state-owned participation shareholders and the environmental governance level of private enterprises. The results show that when private enterprises belong to non-industrial enterprises, state-owned participation shareholders (*State1* and *State2*) do not play a role in the environmental governance level of private enterprises. While, when the private enterprises belong to industrial enterprises, the coefficients of state-owned participation shareholders (*State1* and *State2*) are significantly positive at the 1% level, while comparing the group differences of the coefficients reveals that the coefficients are restrictively different between the two groups. The above results indicate that the environmental pollution caused by the industrial enterprises themselves is serious, and when state-owned participation shareholders are introduced, the state-owned participation shareholders will pay more attention to the environmental issues of the enterprises and exert a supervision effect, which makes the private enterprises to make environmental investments and have a more significant effect on the environmental governance level, which supports Hypothesis 2.
2) Group tests of regional marketization levels. Table 6 reports the difference in the effect of state shareholders on the environmental

TABLE 4 Analysis of main regression results.

Variable	(1)	(2)	(3)	(4)
State1	.053*** (4.68)	.043*** (3.74)		
State2			.664*** (4.19)	.662*** (4.27)
Age		−.027 (−1.60)		−.029* (−1.73)
Size		.041*** (5.37)		.044*** (5.79)
Growth		−.005 (−.23)		−.006 (−.28)
ROA		−.365*** (−3.60)		−.367*** (−3.63)
Lev		.146*** (3.89)		.144*** (3.82)
Capx		1.210*** (8.14)		1.212*** (8.14)
Cfo		.014 (.53)		.016 (.62)
INSR		.000 (.51)		.000 (.18)
Board		−.057* (−1.74)		−.061* (−1.88)
Indp		−.293** (−2.36)		−.286** (−2.31)
Dual		.026** (2.15)		.026** (2.18)
HHI		1.865 (1.02)		1.671 (.92)
ER		.040*** (4.20)		.041*** (4.31)
_cons	−.087*** (−3.69)	−.898*** (−5.03)	−.077*** (−3.32)	−.949*** (−5.27)
Industry/Year	Yes	Yes	Yes	Yes
N	10,436	10,436	10,436	10,436
R-squared	.0156	.0413	.0155	.0419

***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively; t-values are in parentheses, same as in the table below.

TABLE 5 Group test of the industry heterogeneity of private enterprises.

	(1)	(2)	(3)	(4)
	Non-industrial enterprises	Industrial enterprise	Non-industrial enterprises	Industrial enterprise
State1	.010 (.55)	.051*** (3.86)		
State2			.047 (.15)	.852*** (4.79)
Control	Yes	Yes	Yes	Yes
_cons	.088 (.36)	−1.106*** (−4.26)	.076 (.32)	−1.153*** (−4.42)
Industry/Year	Yes	Yes	Yes	Yes
N	1995	8,441	1995	8,441
r2	.0907	.0471	.0905	.0483
Between-group variation	.001***		.011**	

Empirical *p*-values are used to test the significance of differences in State coefficients between groups, obtained by auto sampling (Bootstrap) 1,000 times.

governance level when private enterprises are located in different regions with different levels of marketization. The regression results show that the coefficients of state-owned participation shareholders (*State1* and *State2*) are positive in different subgroups, but only in the group with a high degree of marketization is significant at the 1% level. This indicates that when the location of private enterprises is in a region with a high degree of marketization, the introduction of state-owned participation shareholders can supervision the environmental governance of enterprises and intervene in their business and investment activities from the perspective of internal enterprise governance, which greatly increases the willingness of private enterprises to protect the environment and forces them to invest in environmental governance. Hypothesis 3 was verified.

TABLE 6 Group test of the degree of marketization of the region in which private enterprises are located.

	(1)	(2)	(3)	(4)
	Low level of marketization	High degree of marketization	Low level of marketization	High degree of marketization
State1	.026 (1.50)	.049*** (3.32)		
State2			.068 (.33)	.923*** (4.34)
Control	Yes	Yes	Yes	Yes
_cons	−.975*** (−3.62)	−.770*** (−3.19)	−1.018*** (−3.75)	−.832*** (−3.42)
Industry/Year	Yes	Yes	Yes	Yes
N	5,173	5,263	5,173	5,263
r2	.0581	.0466	.0577	.0498
Between-group variation	.355		.008***	

TABLE 7 Robustness test results1.

	Replacing the dependent variable *LnEI*		Replacement regression model (Logit)		After PSM match	
	(1)	(2)	(3)	(4)	(5)	(6)
State1	.494*** (4.18)		.235*** (.00)		.427*** (3.75)	
State2		7.717*** (4.89)		3.319*** (.00)		.661*** (4.26)
Control	Yes	Yes	Yes	Yes	Yes	Yes
_cons	−12.48*** (−6.26)	−13.07*** (−6.55)	−6.64*** (.00)	−6.97*** (.00)	−9.10*** (−5.07)	−.96*** (−5.31)
Industry/Year	Yes	Yes	Yes	Yes	Yes	Yes
N	10,435	10,435	10,392	10,392	10,423	10,423
R-squared	.0665	.0673			.0414	.0420
Pseudo R2			.0671	.0678		

5 Robustness tests

To ensure the reliability of the study findings, we conducted the following robustness tests.

1) Replacement of the measure of the dependent variable. In the above regressions, the explanatory variable environmental governance level (*EI*) is measured by the relative amount of environmental protection investment after deflating total assets. To maintain the robustness of the results, referring to (Zhou and Shen, 2019), we use the natural logarithm of environmental protection investment to measure the environmental governance level again. The empirical results are shown in columns 1) and 2) of Table 7, and the main findings still hold after replacing the measure of the environmental governance level.
2) Replace the regression model and use the Logit model to test the sample again. In our research sample, there are still many private companies that have not made environmental investments. Therefore, we construct dummy variables based on whether the enterprise environmental investment is zero or not and use the Logit model to test again. The empirical results are shown in columns 3) and 4) of Table 7, and the main findings still hold after replacing the regression model.
3) Propensity score matching (PSM). We use the propensity score matching method to find paired samples for the sample with state-participating shareholders and retest the basic hypothesis using propensity score matched samples. The empirical results of the nuclear-matched screened samples show that the standardized deviations of the variables are all less than 10%, indicating that they pass the balance test. The results for the regression-matched sample are presented in columns 5) and 6) of Table 7 and it can be found that the main findings still hold.
4) The dependent variables are treated with a one-period lag. Since environmental governance takes a long time and therefore has the characteristic of lagging, the regression results are observed after lagging the dependent variable environmental governance level by one period. The results in columns 1) and 2) of Table 8 show that the main findings still hold.
5) Heckman's two-stage approach. Considering the potential sample selection bias problem, not all private enterprises in the sample

TABLE 8 Robustness test results2.

	Dependent variables lagged by one period (*LagEI*)		Heckman two-stage approach	
	(1)	(2)	(3) Phase I (Probit)	(5) Phase II
State1	.052*** (3.91)			.035*** (3.05)
State2		.785*** (4.33)		
Regional industry average			20.390*** (17.18)	
Imr				−.138*** (−3.96)
Control	Yes	Yes	Yes	Yes
_cons	−1.10*** (−5.23)	−1.16*** (−5.47)	−5.37*** (−11.66)	−.32 (−1.44)
Industry/Year	Yes	Yes	Yes	Yes
N	8,463	8,463	10,430	10,430
R-squared	.0395	.0401		.0427
adj. R^2				.0386
Pseudo R2			.0901	

have state-owned participation shareholders, and for enterprises that do not have state-owned participation shareholders, the effect of state-owned participation shareholders on their environmental governance level cannot be observed. To address this issue, we use the Heckman two-stage method to test the sample again. In the first stage process, the average of the shareholding ratios of state-owned participation shareholders in different industries in each region is chosen as the instrumental variable to build the Probit model. In the second stage, the inverse Mills ratio (*Imr*) is brought into the equation for regression. As the results in columns 3) and 4) in Table 8 show, the coefficients of the instrumental variables in the first stage are significantly positive. After accounting for the sample selection bias issue, the coefficient of the regression on the presence of state-owned participation shareholders (*State1*) in the second stage is significantly positive, indicating that the original regression results are still robust and plausible after accounting for the sample selection bias issue.

6 Further research

6.1 The substitution effect of state-owned participation shareholders, executive team's participation in politics, and party organization establishment

State-owned participation shareholders (government-owned equity), executive team's participation in politics (private entrepreneurs have certain political status and identity) and Party organization establishment are the same explicit political association of private enterprises, and there is a substitution relationship among them (Zhang and Guo, 2010; Deng and Wang, 2020). State-owned participating shareholders are the shares formed by relevant departments or institutions that have the right to invest on behalf of the state with state-owned assets in the entity company, including shares converted from the company's existing state-owned assets; the political participation of the executive team is mainly reflected in the political identity of private entrepreneurs including the political identity of the chairman or CEO and their background as government officials, which can enable the company to maintain direct or indirect relations with the government; According to Article 19 of the Company Law, private enterprises should establish party organizations with reference to the Communist Party's constitution to supervise and guide the enterprises' business activities and facilitate communication with the government (Zhang and Jiang, 2019). In terms of environmental governance, relevant studies have shown that private enterprises with executive teams participating in politics have relatively more environmental governance levels (Lin et al., 2015; Xu and Yan, 2020), and Party organization establishment plays an effective supervisory role, which makes private enterprises' activities more guided and restricted by the government and more actively respond to the national green development strategy, invests more resources in pollution control and environmental protection (Yan and Xu, 2022). The executive team's participation in politics and Party organization establishment is a kind of proactive behavior of enterprises, which try to establish relationships with government departments or officials through these means to pursue their interests. In contrast, political affiliation at the equity level of state-owned participation shareholders can more directly and effectively improve the environmental governance of the enterprise. The introduction of state-owned participation shareholders into private enterprises is based on existing laws and institutions, and state-owned equity shareholders are both passive and active. In this case, government departments form a community of interest with private enterprises, forming a more stable and close institutional link with private enterprises at the equity level, and a more direct political association (Li et al., 2021). In practice, government departments, as external stakeholders and capital market participants of private enterprises, often play a crucial role (Yu

TABLE 9 Test for the substitution effect of state-owned participation shareholders, executive team's participation in politics, and Party organization establishment.

	(1)	(2)	(3)	(4)
State1	.040*** (3.12)		.026 (1.55)	
State2		.620*** (3.63)		.606 ** (2.15)
PC × State1	.030 (1.44)			
PC×(1- State1)	.024* (1.66)			
PC × State2		.151 (.42)		
PC×(1- State2)		.024* (1.87)		
Party× State1			.047** (2.44)	
Party×(1- State1)			.021* (1.67)	
Party× State2				.063 (.19)
Party×(1- State2)				.029*** (2.61)
Control	Yes	Yes	Yes	Yes
_cons	−.892*** (−5.01)	−.941*** (−5.24)	−.836*** (−4.70)	−.8912*** (−4.97)
Industry/Year	Yes	Yes	Yes	Yes
N	10,436	10,436	10,436	10,436
R-squared	.0418	.0424	.0422	.0426

et al., 2017). Therefore, when state-owned participation shareholders are introduced, government departments are more effective in supervising private enterprises, thus improving enterprise environmental governance.

To explore the above issue, referring to Deng and Wang (2020), the State variable is put into the regression model in a model (2) and two interaction terms *PC × State* and *PC × (1- State)*, *Party × State* and *Party × (1- State)* are added for regression, respectively, to create the following model.

$$EI_{i,t} = \alpha_0 + \alpha_1 State_{i,t} + \alpha_2 PC \times State_{i,t} + \alpha_3 PC \times (1 - State_{i,t}) + \alpha_4 Contorl_{i,t} + \varepsilon_{i,t} \quad (2)$$

$$EI_{i,t} = \beta_0 + \beta_1 State_{i,t} + \beta_2 Party \times State_{i,t} + \beta_3 Party \times (1 - State_{i,t}) + \beta_4 Contorl_{i,t} + \varepsilon_{i,t} \quad (3)$$

Among them, The subscripts i and t represent the firm and year, respectively, and ε is the model residual. *PC* is a dummy variable indicating whether there is an executive team's participation in politics, which is defined by (Yu and Pan, 2008) and is considered to exist if the general manager or chairman of a privately listed company is or has been serving in a government department, elected as a deputy to the National People's Congress and a member of the Chinese People's Political Consultative Conference, and is assigned a value of 1, otherwise 0. Party organization establishment, using the approach of (Zhang and Jiang, 2019), takes the value of 1 if the private enterprise has established a grassroots Party organization in the current year, and 0 otherwise. In models (2) and (3), we focus on the coefficient values α_3 for *PC × (1- State)* and β_3 for *Party × (1- State)*. If both α_3 and β_3 are significantly greater than 0, it indicates that in terms of improving the environmental governance level of private enterprises, there is a substitution relationship between the state-owned participation shareholders and the executive team's participation in politics and the Party organizations establishment.

Table 9 shows the regression results of the alternative relationship between state-owned participation shareholders and the executive team's participation in politics and Party organization establishment, where columns 1) and 2) are the regression results of the alternative relationship between state-owned participation shareholders and executive team's participation in politics and model (2), and columns 3) and 4) are the regression results of the alternative relationship between state-owned participation shareholders and Party organization establishment and model (3). The test results show that in columns 1), 2), and 4) the coefficients of the cross-product terms *PC×State* and *Party×State2* are positive but insignificant, and the regression coefficients of the cross-product terms *PC×(1- State)* and *Party×(1- State2)* are positive and all pass the significance test. In column 3), the coefficients of the cross-products *Party×State1* and *Party×(1- State1)* are positive and pass the significance test. In addition, the effects of control variables in models (2) and (3) are approximately the same as in model (1). This result indicates that when state-owned equity shareholders participate in private enterprises, they can promote environmental investment and improve environmental governance. In this case, enterprises significantly reduce their reliance on the executive team's participation in politics and Party organization establishment. However, in the absence of state-owned participation shareholders in private enterprises, the role of the executive team's participation in politics and Party organization establishment in improving the environmental governance level is greater, i.e., there is a substitution effect between state-owned participation shareholders and executive team's participation in politics and Party organization establishment in promoting the environmental governance of enterprises. At the same time, the political affiliation effect brought by state-owned participation shareholders plays a much

TABLE 10 Results of further analysis.

	(1)	(2)
	EI	*EI*
Local	.050** (2.16)	
Part		.072*** (3.05)
Control	Yes	Yes
_cons	−1.464*** (−4.87)	−1.343*** (−4.54)
Industry/Year	Yes	Yes
N	4,271	4,271
adj. R^2	.0666	.0678

larger role than the executive team's participation in politics and Party organization establishment.

6.2 The relationship between the origin of state-owned participation shareholders, the degree of participation, and the environmental governance level

According to the previous arguments and analysis, state-owned equity shareholders can improve the level of enterprise environmental governance. Then, what type of state-owned participation shareholders has a more significant effect on the environmental governance level of private enterprises? (Luo and Qin, 2019)? Find that the impact of state-owned participation shareholders on private enterprises depends not only on the number of state-owned participation shareholders' shareholdings in private enterprises but also on the place of origin of state-owned participation shareholders and their level of participation in private enterprises.

In terms of the origin of the participating shareholders, when the state-owned participation shareholders and the private enterprises come from the same region, the closer the geographical distance between them, the lower the communication cost and the greater the influence on the private enterprises. When the state-owned participation shareholders originate from the local area, private enterprises will meet government needs, respond positively to government policy guidelines, improve the ecological environment of the enterprise, and make environmental investments, thus obtaining the key resources allocated by the local government. From the perspective of shareholder participation, the "formal" participation of state-owned equity shareholders in private enterprises can have a limited impact, but only "substantive" participation in the daily business activities of the enterprise can have a real impact. Therefore, when there are strong representatives of state-owned participation shareholders in private enterprises, it is often more conducive to the supervision effect, alleviating the internal agency conflict of the controlling private enterprises, and the connection between enterprises and government departments is also closer (Li et al., 2017). Therefore, local state-owned participation shareholders are more likely to improve the environmental governance of private enterprises than off-site state-owned participation shareholders; compared with the low participation in private enterprises, the higher participation of state-owned shareholders has a more significant effect on the improvement of the environmental governance level of private enterprises.

Based on the above analysis, we further explore the benchmark results by distinguishing the characteristics of the origin and degree of participation of state-owned participation shareholders. Specifically, we restrict the sample to private enterprises with state-owned participation shareholders and construct the following regression model.

$$EI_{i,t} = \alpha_0 + \alpha_1 Local_{i,t} + \alpha_2 Contorl_{i,t} + \varepsilon_{i,t} \tag{4}$$

$$EI_{i,t} = \beta_0 + \beta_1 Part_{i,t} + \beta_2 Contorl_{i,t} + \varepsilon_{i,t} \tag{5}$$

where i and t represent the enterprise and year, respectively, and ε is the model residual. Referring to (Luo and Qin, 2019), when the number of shares held by local state-owned participation shareholders is more among state-owned participation shareholders, the state-owned participation shareholders are considered to be of local origin and *Local* takes the value of 1, otherwise, it takes the value of 0. When state-owned participation shareholders send directors to private enterprises, the state-owned participation shareholders are considered to have a high degree of participation in private enterprises and *Part* takes the value of 1, otherwise, it takes the value of 0. In models (4) and (5), we focus on coefficient value α_1 for $Local_{i,t}$, and coefficient value β_1 for $Part_{i,t}$, which respectively measure the impact of the origin and participation degree of state-owned shareholders on the environmental governance level of private enterprises.

Table 10 reports the differences in the impact of the origin of state-owned participation shareholders and the participation degree of state-owned participation shareholders on the environmental governance level among private enterprises with state-owned participation shareholders. Among them, column 1) shows the difference in the impact of the participation of state-owned participation shareholders on the environmental governance level of private enterprises when the origin of the shareholders is different. The results show that the coefficient of whether the state-owned participation shareholders are from local (*Local*) is .050 and significant at the 5% level, which means that when the state-owned equity participation is from local, it has a stronger effect on the environmental governance level of private enterprises; column 2) shows the difference in the effect of its participation on the environmental governance level of private enterprises when the state-owned participation shareholders have different degrees of participation. The coefficient of the degree of participation (*Part*) is .072, which is also significant at the 1% level, indicating that when the participation degree of state-owned participation shareholders in private enterprises is high, their participation has a stronger effect on the improvement of the environmental governance level of private enterprises.

7 Conclusion and recommendations

The introduction of state-owned participation shareholders in private enterprises gives them significant resource acquisition advantages but also gives them more social functions. We examine the impact of state-owned participation shareholders on the environmental governance level of private enterprises from the supervision effect hypothesis. The results show that state-owned participation shareholders can improve the environmental governance level of private enterprises, and the improvement effect is more significant when the enterprise is an industrial enterprise and registered in regions with a higher degree of marketization. Further analysis reveals that there is a substitution effect between the state-owned participation shareholders, the executive team's participation in politics, and the Party organization establishment in improving the environmental governance level of private enterprises, and the state-owned participation shareholders play a relatively larger role; from the characteristics of state-owned participation shareholders, when the state-owned participation shareholders are of local origin and have a high participation degree, the role of state-owned participation shareholders in improving the environmental governance level of private enterprises is more significant. Our study expands the research in the area of economic consequences for state-owned participation shareholders from the perspective of corporate environmental governance, enriches the literature on the factors influencing enterprise environmental governance, and provides an empirical basis for private enterprises to further deepen the mixed-ownership reform at this stage, which is of great significance for achieving the policy goal of ecological civilization construction.

Based on the above research findings, we propose the following policy recommendations: 1) Actively promote state-owned equity shareholders' participation in private enterprises. The unique sense of environmental responsibility of state-owned participation shareholders helps to urge private enterprises to make environmental investments, so the supervisory effect of state-owned participation shareholders should be given full play to promote the company to improve its governance structure and optimize its environmental governance decision-making mechanism. 2) State-owned equity should participate in private enterprises for different industries and regions. By tilting limited resources to industrial enterprises and enterprises in regions with a high degree of marketization and improving the supervision efficiency of state-owned participation shareholders, it will help to better realize the effective integration of different mixed economies and improve the environmental governance level of private enterprises. 3) State-owned participation shareholders should not only participate in private enterprises but also participate in the management decisions of private enterprises. Only when the state-owned participation shareholders have a real influence on private enterprises can they effectively play their role in the governance of private enterprises. Therefore, state-owned participation shareholders should pay attention to the "form" and "substance" of equity participation, and participate in the "substance" of the private enterprise's business management decisions.

The shortcomings of this paper and the corresponding research directions are mainly reflected in the following three aspects: First, due to the availability of data, our samples are all listed companies in the private sector. However, state-owned participation shareholders also exist in a large number of unlisted companies, which are also the main force of environmental governance. Therefore, in future research, we can obtain data from non-listed companies through various channels, such as field research, to study the influence of state-owned participation shareholders on the environmental governance level in non-listed private companies. Second, there is no unified standard for measuring the environmental governance level in the existing literature, and only environmental investment data are used to measure it in our study. Environmental investment belongs to the perspective of input, and the data are manually collected and compiled by us through reviewing the company's financial statements and social responsibility reports, which have some errors. In the follow-up study, we can consider how to better measure the enterprise environmental governance level from both input and output perspectives. Finally, we have only examined the effect of the shareholding of state-owned participation shareholders and the shareholding ratio of state-owned participation shareholders on the environmental governance level of private enterprises, and have not yet examined the effect of different types of state-owned participation shareholders on the environmental governance level of private enterprises. In future research, we can further distinguish between national-level participation shareholders, provincial-level participation shareholders, and investment-type platform participation shareholders to explore in depth the impact of state-owned participation shareholders on the environmental governance level of private enterprises.

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

Conceptualization, LZ and JM; methodology, LZ and JM; software, JM; validation, LZ and JM; formal analysis, LZ and JM; investigation, LZ and JM; resources, JM; data curation, JM; writing—original draft preparation, JM; writing—review and editing, LZ and JM; visualization, LZ and JM; supervision, LZ; project administration, LZ and JM. All authors have read and agreed to the published version of the manuscript.

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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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The impact of export tax rebate reform on industrial exporters' soot emissions: Evidence from China

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In this paper, we systematically explore the environmental effects of the export tax rebate rate reduction policy using the China Industrial Enterprise Database, the China Industrial Enterprise Pollution Database, and the China Customs Import and Export Database from 2005 to 2013. Our difference-in-difference (DID) estimates show that the reduction in the export tax rebate rate significantly reduces the intensity of corporate soot emissions, and this finding holds after a series of robustness tests. For every 1-unit reduction in export tax rebate rate, industrial exporters' soot emission intensity decreases by 2.63%. The mechanism analysis shows that the decrease in soot generation, the decrease in coal use intensity, the increase in total amount and efficiency of soot treatment are important channels. Heterogeneity analysis shows that the reduction of export tax rebate rate has a more significant impact on the intensity of soot emissions of high pollution, high energy consumption and resource-based enterprises. This study may provide a reference for other developing countries that also rely on export tax rebates to adjust their policies to combine economic growth with pollution control.

KEYWORDS

export tax rebate, China, soot emissions, industrial exporters, DID method

1 Introduction

Since the reform and opening up in 1978, China's foreign trade has grown rapidly. By the end of the 20th century, China had become an important global trading country and successfully joined the WTO in 2001 (Hu and Tan, 2016; Yu and Luo, 2018; Kong et al., 2021; Xu et al., 2022). Many scholars attribute the growth of China's exports to China's export promotion policies, of which the export tax rebate policy is an important one (Chandra and Long, 2013; Lee et al., 2021). The export tax rebate policy is to encourage the development of export trade in China by refunding the VAT and excise tax paid in the domestic production and operation of export goods in accordance with the tax law (Song et al., 2015). Export rebates are often adjusted to promote or discourage the export of certain products. In fact, besides China, countries such as South Korea, Pakistan, Bangladesh, Malaysia, Brazil and Mexico also use export tax rebate policy as an important tool to promote foreign trade (Mah, 2007; Ahmed et al., 2014; Ayob and Freixanet, 2014).

Along with the rapid expansion of foreign trade, the environmental pollution problems caused by export enterprises have become increasingly serious. Many empirical studies have concluded that the emissions of Chinese exports are significant (Peters et al., 2007; Peters and Hertwich, 2008; Weber et al., 2008; Zhang, 2012). Among the various factors that increase trade expansion and related pollution, export tax rebates have played an important role, particularly in highly polluting sectors such as "leather products", "paper products", "petroleum and coke products", "chemical, rubber, and plastic products" and "ferrous metals" (Song et al., 2015).

The Chinese government has long been aware of the need to promote green trade development and has tried to find feasible solutions to improve the quality of trade exports and reduce environmental pollution. In terms of export tax rebate rate policy, as early as 1995, China reduced the export tax rebate rate for coal and industrial products in the hope of improving carbon emissions and environmental pollution. However, in 1998, due to the financial crisis and in order to stimulate trade development, the Chinese government increased the export tax rebate rates for coal, steel, aluminum and some metal raw materials (Jiang and Chen, 2020). In 2005, in order to adjust the product structure of foreign trade and encourage the increase of the proportion of trade exports of environment-friendly enterprises, China reduced the export tax rebate rates of some highly polluting, energy-consuming and resource-based products. At the same time, the export tax rebate rates for IT products and pharmaceutical products were raised to stimulate the trade competitiveness of low energy-consuming and innovative enterprises (Xu, 2018; Braakmann et al., 2020). In 2007, the Chinese central government adjusted the export tax rebate policy again. The purpose of this large-scale policy adjustment is to promote sustainable economic development and environmental protection, and to curb the development of resource-based and highly polluting trade industries. Specifically, the scope of this export tax rebate policy adjustment involves 37% of all goods in the customs, and 553 export tax rebates for highly polluting, energy-consuming and resource-based goods have been cancelled. China's average export tax rebate rate was reduced by 5.9%, and the export tax rebate rate for highly polluting, energy-consuming and resource-based products, such as part of steel and chemicals, was reduced by 11.1% (Song et al., 2015).

In this paper, we analyze the environmental effects of export tax rebate rate reduction based on the DID method using the China Industrial Enterprise Database, the China Industrial Enterprise Pollution Database, and the China Customs Import and Export Database from 2005 to 2013. The regression results show that the reduction of export tax rebate rate significantly reduces industrial exporters' soot emissions, and this conclusion still holds after a series of robustness tests. For each 1-unit decrease in export tax rebate rate, industrial exporters' soot emission intensity decreases by 2.63%. The mechanism analysis shows that the reduction of export rebate rate leads to the reduction of pollution emission, the reduction of coal use intensity, the increase of pollution treatment and the increase of soot treatment per hour, which in turn leads to the reduction of soot emission intensity of industrial enterprises. Heterogeneity analysis shows that the reduction of export tax rebate rate has a more significant impact on the intensity of soot emissions of high pollution, high energy consumption and resource-based enterprises.

To the best of our knowledge, this is the first study that utilizes longitudinal data to empirically examine the impact of export tax rebate reform on industrial exporters' soot emissions in China. We enrich the existing literature in the following aspects: 1) This study examines the impact of environmental export tax rebate policy on enterprises' emission behavior at the micro-enterprise level by using unique data on enterprises' production, export and emission. 2) We innovatively use a comprehensive soot emission indicator as the dependent variable, which is different from previous literature that uses indicators such as carbon dioxide and sulfur dioxide as proxy variables to measure enterprises' emission. 3) Based on the heterogeneity of the impact of export tax rebate policy on the emission behavior of enterprises with different property rights and industries, this paper further classifies the sample by property nature and industry.

The remainder of this paper is organized as follows. Section 2 presents a review of the existing literature on the subject. Section 3 introduces the data and identification strategy. Section 4 reports the main empirical results. Section 5 presents the discussions. Finally, concluding remarks on policy implications are summarized in Section 6.

2 Literature review

2.1 The impact of export tax rebates on trade

Most of the available literature has concluded that export tax rebate policies have a positive trade promotion effect (Chen et al., 2006; Mah, 2007; An et al., 2017; Bao et al., 2017; Liu and Ge, 2018; Zhang, 2019). Chao et al. (2001) studied the impact of export tax rebates on trade by developing a general equilibrium model using Chinese data from 1985 to 1999 and found that there was a significant export promotion effect of export tax rebates in the short run. Using a partial equilibrium model, Chen et al. (2006) found that export tax rebates increased the output and profits of domestic exporters and that China's net exports and foreign exchange reserves showed a significant positive relationship with export tax rebate policy. Mah (2007) examined the effectiveness of the tax rebate system in promoting exports in Korea, where the development strategy was often characterized as export-led growth, assuming infinite elasticity of export demand, and found that the tax rebate system contributed significantly to export promotion. Zhang (2019) assessed the impact of export tax rebates on firms' total factor productivity using a panel of large manufacturing firms in China from 2007–2015 and found that export tax rebates expanded firms' exports and acted as an alternative financial channel to increase firms' total factor productivity. Zhang et al. (2022) examined the relationship between export tax rebates and productivity using firm-level data for China from 2000 to 2007. They found that a one-percentage-point reduction in the export tax rebate rate could increase a firm's total factor productivity (TFP) by about .1 percentage points.

The export tax rebate policy is actually a preferential tax policy to encourage exports. However, the impact of different tax policies on exports is different. Nguyen (2014) found that tariff reductions following 12 bilateral FTAs and one regional FTA between Japan and countries such as Singapore, Mexico, and Malaysia had increased the scale of product exports. Mai and Stoyanov (2015) examined the impact of CUSFTA on Canadian trade flows and found that a .3%–.35% reduction in tariff levels significantly contributed to Canadian trade growth. Sun et al. (2020) combined a multisectoral dynamic computable general equilibrium model with an ecological footprint evaluation and found that energy taxes increased the export of the ecological footprint but reduced its import.

2.2 Environmental impacts of trade

The pollution halo hypothesis and the pollution haven hypothesis are the two representative inconsistent views regarding the impact of trade on the environment. The pollution halo hypothesis suggests that trade will lead to environmental improvement because foreign trade will bring advanced technology and management experience to developing countries, which in turn will improve their production methods and integrated environmental management (Bokpin, 2017; Singhania and Saini, 2021). Tsai (1999) used a partial equilibrium strategic trade framework to show that trade liberalization can improve environmental quality. Antweiler et al. (2001) developed a theoretical model to divide trade's impact on pollution into scale, technique, and composition effects and then examined this theory using data on sulfur dioxide concentrations. They found that trade liberalization appeared to be good for the environment. Eskeland and Harrison (2003) found that multinational firms were more energy efficient and more likely to adopt clean energy than local firms using data from Mexico, Côte d'Ivoire, Morocco and Venezuela. Asghari (2013) reached similar conclusions using data from the Middle East and North Africa. Xu et al. (2022) analyzed the impact of foreign trade on green total factor energy efficiency in China using panel data for 30 provinces from 2004–2017, and the results of the spatial Durbin model suggested that an increase in imports not only led to economic growth, but also had a positive impact on regional green total factor energy efficiency.

In contrast, according to the pollution haven hypothesis, developed countries will use outward investment to shift their pollution-intensive industries to developing countries with less stringent environmental regulations to avoid the increase in production costs of polluting industries due to stringent environmental regulations in their countries (Acharyya, 2009). Chung (2014) studied the investment and trade data of the industrial sector in Korea and found that polluting industries tend to move to countries with less stringent environmental regulations. Bokpin (2017) used 24 years of panel data (1990–2013) for Africa to investigate the impact of FDI inflows on ecosystems. The combined empirical results showed that increased FDI inflows significantly exacerbated environmental degradation and negatively affected environmental sustainability. Bu et al. (2019) argued that pollution-intensive industries and industries with low levels of environmental protection were more likely to invest in countries or regions with less stringent environmental regulations, and multinational companies with high environmental protection technologies tended to invest in regions with higher environmental regulations, so countries or regions with lax environmental regulations became pollution havens; Zhang (2019) found that trade benefited developed countries, but increased CO2 emissions in developing countries; Tachie et al. (2020) explored the impact of trade openness in developed countries using 18 EU economies. Mean group (MG) and augmented mean group (AMG) results showed that trade openness increases co2 emissions in the EU18. Using a time series dataset for Uruguay from 1980 to 2018, Awosusi et al. (2022) found that trade liberalization had a catalytic effect on CO2 emissions in both the long and short term, and that Uruguay's economic expansion had worsened environmental quality in both the long and short term.

2.3 Environmental impact of export tax rebates

From the previous literature review, it is clear that export tax rebates affect trade, and trade affects the environment, so changes in export tax rebates may affect the environment. Some scholars believe that the export tax rebate policy can be an important tool for environmental protection. For example, Song et al. (2015) analyzed the effectiveness of export tax rebate adjustments aimed at alleviating environmental pressure in different periods by means of a computable general equilibrium model. They found that before 2003, high polluting sectors enjoyed higher than average export rebates leading to an increase in pollution emissions, and between 2003 and 2010, the export rebate system reduced support for high polluting export sectors leading to a decrease in emissions. Eisenbarth (2017) used a general equilibrium model for empirical testing and found that the VAT rebate rates were set in a way that discouraged exports of water pollution intensive, SO2 intensive and energy intensive products from 2007 on.

Some other scholars argue that changes in export tax rebate refund policies have a limited effect on environmental protection. For example, By applying a CEEPA (China Energy and Environmental Policy Analysis system) model, Fan et al. (2015) simulated the impacts of the cancellation of export rebates on CO2 emissions and socio-economic consequences, and believed that the export tax rebate policy has a limited role in environmental protection and should not be used as an important tool for environmental protection.

Since export tax rebate policy is one kind of tax policy, the analysis of the impact environment of other tax policies can also provide us with some insights. As a representative tax closely related to the environment, scholars have done a lot of research on environmental tax. Most studies have concluded that environmental taxes can improve environmental quality (Sterner, 2007; Wissema and Dellink, 2007; Lin and Li, 2011; Borozan, 2019). Convery et al. (2007) concluded that environmental taxes may generate $13 billion in revenue for the Irish economy and lead to a 90 percent drop in Ireland's carbon dioxide emissions. Piciu and Trică (2012) examined the environmental tax and CO2 emissions nexus in EU member nations, and found the inverse relationship between environmental taxes and CO2 emissions. He et al. (2019) also found the influential role of environmental taxes in minimizing the CO2 emissions in OECD economies and China. Wolde-Rufael and Mulat-Weldemeskel (2021) assessed the effectiveness of environmental taxes and environmental policy instruments in reducing CO2 emissions in seven emerging economies over the period 1994–2015, and found that strict environmental policies and environmental taxes were effective in reducing CO2 emissions. Based on data from Chinese listed companies from 2010 to 2019, Wang C et al. (2022) developed an evaluation system for corporate green innovation and found that tax incentives promoted corporate green innovation. However, a few studies have concluded that environmental control policies such as environmental taxes are not effective on the environment. Using interprovincial panel data from 2001–2013, Li and Liu (2015) found that the collection of pollution fees may cause an increase in industrial pollution emissions. Wang and Wei (2020) employed the panel smooth transition regression technique and found that stringency environmental policy does not improve environmental quality by reducing CO2 emissions.

A review of the existing literature reveals that there is no consensus on the study of the environmental effects of trade policies. More importantly, empirical studies on the environmental effects of export tax rebate policies are still relatively few, and the existing literature on the environmental effects of export tax rebates mainly focuses on the macro level, lacking firm-level analysis. This paper empirically investigates the impact of export tax rebate policy on the environmental behavior of enterprises, making a marginal contribution to the existing research on the environmental effects of export tax rebate policy.

TABLE 1 Descriptive statistics.

Variables	Measurement	Observations	Mean	S.D.	Min	Max
Lnsootdensity	Ln (soot emission/the total industrial output value)	61,904	−7.498	4.267	−18.65	13.73
Lnsootdensity1	Ln (soot emission/the new total industrial output value)	61,946	−4.587	4.323	−15.90	14.86
Post	It takes the value of 0 before 2007 and 1 afterwards	93,420	.826	.379	0	1
Retaxgap	Reduced export tax rebate rate for the company's largest selling product (%)	93,420	2.955	3.912	0	13
Retaxgap1	Weighted average of the reduction in the company's tax rebate rate for different products (%)	93,406	2.972	3.741	0	13
Stateowned	Which takes the value of 1 if state-owned and 0 if non-state-owned	93,420	.108	.311	0	1
Firmsize	Ln (total enterprise assets)	93,415	11.88	1.586	0	19.44
LnKL	Ln (number of employees/the net value of fixed assets)	92,496	4.500	1.468	−10.20	14.72
Lnage	Ln (firm survival years)	93,410	2.286	.710	0	5.081
LEV	Total liabilities/Total assets	93,367	.551	.287	−.891	18.38
Provocatory	The value is 1 for the provinces implementing the sewage charge policy, otherwise 0	93,420	.187	.390	0	1
Lnsootdischarge	Ln (corporate soot emissions)	62,103	4.6162	3.9584	0	17.0483
Lncoal	Ln (corporate coal use)	36,317	5.8577	3.6716	0	16.4175
Lnsoottreat	Ln (corporate soot treatment)	17,170	2.2109	4.6439	0	21.6664
Lntreatefficiency	Ln (the amount of soot treated per hour)	40,132	7.6499	4.0107	0	21.6025

Note: The total industrial output value and the new total industrial output value are taken from the China Industrial Enterprise Database and the Industrial Enterprise Pollution Emission Database, respectively.

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TABLE 2 Impact of the reduction of export tax rebate rate on industrial exporters' soot emission intensity.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	Lnsootdensity	Lnsootdensity	Lnsootdensity	Lnsootdensity	Lnsootdensity	Lnsootdensity
Retaxgapi × $Post_t$	−.0314***	−.0317***	−.0266***	−.0258***	−.0259***	−.0263***
	(.0098)	(.0098)	(.0095)	(.0095)	(.0095)	(.0096)
Stateowned		.1915**	.1963**	.1970**	.1949**	.2077**
		(.0892)	(.0886)	(.0888)	(.0887)	(.0922)
Firmsize			−.6436***	−.6336***	−.6361***	−.6017***
			(.0450)	(.0473)	(.0473)	(.0511)
LnKL				−.0102	−.0094	−.0176
				(.0158)	(.0158)	(.0216)
Lnage					.0637	.0304
					(.0569)	(.0610)
LEV						−.0539
						(.0666)
Provincepolicy						.2160***
						(.0591)
Year FE	Y	Y	Y	Y	Y	Y
Province FE	Y	Y	Y	Y	Y	Y
Industry FE	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y	Y
Constant	−5.5233***	−5.5262***	2.2369***	2.1535***	2.0897***	1.4720*
	(.3820)	(.3824)	(.6574)	(.6739)	(.6741)	(.8044)
Observations	61,904	61,904	61,900	61,418	61,417	40,056
R-squared	.7036	.7037	.7102	.7075	.7075	.7114

Notes: Robust standard errors for clustering to the firm level are in parenthesis. Year FE, indicates time fixed effects, Province FE, indicates Province fixed effects, Industry FE, indicates Industry fixed effects, and Firm FE, indicates Firm fixed effects. *, **, and *** indicate significant at the 10%, 5%, and 1% levels, respectively.

3 Materials and methods

3.1 Data and variables

Our data were collected from multiple sources. The enterprise-level characteristics were mainly from the China Industrial Enterprise Database (2005–2013), the China Customs Statistics (2005–2013) and the Industrial Enterprise Pollution Emission Database (2005–2013). The China Industrial Enterprise Database records information on the categories, production, and business activities of industrial enterprises above the scale (annual sales of five million RMB before 2011 and 20 million RMB after 2011) (Long et al., 2022). The China Customs Statistics contains the type of ownership of the enterprise, the type of import and export, the HS code, quantity and amount, trade mode and mode of transport of the imported and exported goods, the destination of the exported goods and the place of origin (Bouvet et al., 2017). The Industrial Enterprise Pollution Emissions Database provides information on the output, energy consumption, and pollution emissions of industrial enterprises in China (Zhang et al., 2018).

The purpose of this paper is to examine the impact of export tax rebates on firms' emission behavior. We matched the China Industrial Enterprise Database, the China Customs Statistics and the Industrial Enterprise Pollution Emission Database using the legal person code and the company name to obtain the category, operation, product exports and pollution information at the enterprise level. The specific matching process is as follows: first, the China Industrial Enterprise Database was processed by referring to (Brandt et al., 2012), deleting samples with total revenue, employment, fixed assets, total sales, R&D expenses, and intermediate inputs less than 0, deleting invalid samples with original value of fixed assets less than net value, missing company name or wrong establishment time, deleting non-manufacturing enterprises, deleting employment enterprises with less than eight persons. After that, the data of previous years were combined to form the panel data of industrial enterprises database. Second, we used a similar approach to construct the panel data of Industrial Enterprise Pollution Emission Database. Third, since the export tax rebate policy targets exporters, we only keep the sample of exporters in the customs database. We matched the codes in the list of commodities for which the export tax rebate rates were adjusted by the Ministry of Finance and the General Administration of Taxation with

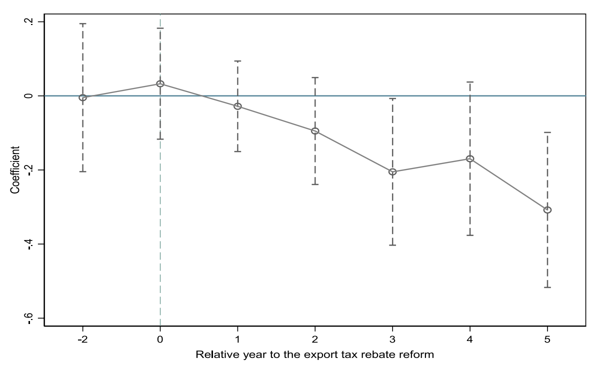

FIGURE 1
Parallel trend test and the dynamic effect analysis of the reduction in export tax rebate rate. *Notes:* The horizontal coordinates indicate the year relative to the export tax rebate reform in 2007. Specifically, 0 indicates the year in which the export tax rebate reform took place, and 1 indicates the first year of the VAT reform. The vertical coordinate indicates the magnitude of the interaction term coefficient, with the dashed line depicting the 95% confidence interval.

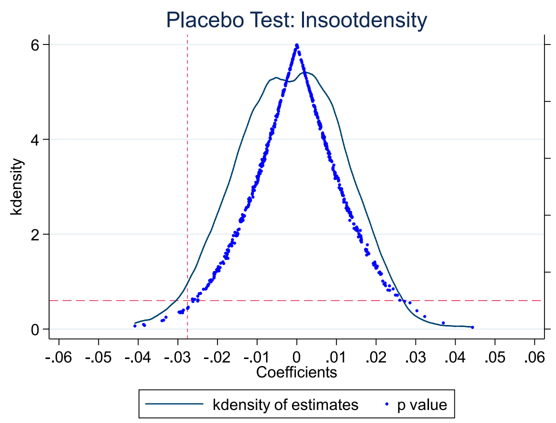

FIGURE 2
Placebo test for export tax rebate reform randomness.

the Harmonized System (HS) 8-bit code, and the reduction of the export product tax rebate rates was equal to the difference between the rates before and after the export tax rebate reform in 2007. How to convert the product-level tax rebate rate to the firm-level tax rebate rate is the key issue to be considered. In this paper, only the products with the largest company sales are retained in the benchmark regressions, and the difference in company-level tax rates is the difference in the tax rate of the product with the largest company sales value before and after 2007. The change in the firm-level export tax rebate rate in the robustness test was then based on the difference in the export tax rebate rates of multiple products before and after the reform multiplied by the weighted average of the ratio of sales of that product to total sales in 2006. After that, the panel data were formed by removing the duplicate observations at the firm level for each year. Finally, the processed panel data of industrial enterprises database, the China Customs Statistics and the Industrial Enterprise Pollution Emission Database were combined according to the unique identifiers formed by the firm identity information to form the panel data needed for regression analysis.

The explained variable in this paper is the emission behavior of enterprises, which is measured by the intensity of soot emissions from enterprises. The soot emission intensity of an enterprise is equal to the soot emission divided by the total industrial output value of the year. The explanatory variable is $Retaxgap_i \times Post_t$, $Retaxgap_i$ denotes the amount of reduction in export tax rebate rate for enterprise i. $Post_t$ denotes the time dummy variable of export tax rebate policy, and $Post_t$ takes the value of 0 if the value of t is before 2007, and $Post_t$ takes the value of one if the value of t is 2007 and after.

Referring to (Chen, 2020), the control variables in this paper including (1) Stateowned, which takes the value of one if an enterprise is state-owned and 0 if non-state-owned. (2) Firmsize, which is the logarithm of the company's total assets. (3) Firmage, which is the year of observation minus the year of firm establishment. (4) KL, which is the net value of fixed assets by the number of employees of the firm. (5) LEV, which is a firm's gearing ratio, is measured by dividing a firm's total liabilities by its total assets. (6) Provocatory, which indicates whether or not the province or municipality where the company is located has conducted a pilot program to increase its sewage charges, taking a value of one if it does, and 0 otherwise.

Table 1 shows the descriptive statistics of the main variables. The average export tax rebate rate of the sample enterprises decreased by 2.95%, with a maximum decrease of 13%. The share of state-owned enterprises was 10.8%, and the average asset-liability ratio was 55.1%.

The intensity of soot emissions depends mainly on the amount of soot produced and treated. To examine the mediating mechanisms by which export rebates affect firms' soot emissions, we introduce four mediating variables. Variables that measure soot production include lnsootdischarge (corporate soot emissions) and lncoal (corporate coal use). Variables that measure soot treatment include lnsoottreat (corporate soot treatment) and Lntreatefficiency (treatment efficiency of soot treatment facilities, measured by the amount of soot treated per hour).

3.2 Methods

To effectively address the endogeneity problem, we construct a DID model to identify the impact of declining export tax rebates on the intensity of soot emissions of Chinese enterprises. The formula is as follows:

$$lnSI_{ijkt} = \beta_1 * Retaxgap_i \times Post_t + \beta_2 * X_{it} + \gamma_i + \mu_j + \delta_k + \lambda_t + \varepsilon_{ijkt} \quad (1)$$

Here, i represents the enterprise, j represents the industry, k represents the province, and t represents the year. The explanatory variable $lnSI_{ijkt}$ denotes the logarithmic value of soot emission intensity of firm i in year t $Retaxgap_i \times Post_t$ is the core explanatory variable of the econometric regression model. β_1 is the coefficient of interest in this paper, which measures the percentage change in the intensity of firms' soot emissions for each unit reduction in export tax rebates. X_{it} are the control variables, including Stateowned, Firmsize, LnKL, Lnage, LEV and Provocatory. γ_i is the firm fixed effect to control for factors that do not vary over time at the firm level. δ_k is the region fixed effect to fix factors that do not vary over time at the region level. μ_j is the industry fixed effect to control for factors that do not vary over time at the industry level. λ_t is a time fixed effect to control for factors that vary over time but not with the firm. ε_{ijkt} is a random error term.

TABLE 3 Impact of export tax rebate rate reduction on the firms' soot emission intensity (Replace explanatory variables).

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	Lnsootdensity	Lnsootdensity	Lnsootdensity	Lnsootdensity	Lnsootdensity	Lnsootdensity
$\text{Retaxgap1}_i \times Post_t$	−.0340***	−.0342***	−.0292***	−.0286***	−.0288***	−.0309***
	(.0099)	(.0099)	(.0096)	(.0096)	(.0096)	(.0100)
Stateowned		.1204	.1150	.1170	.1156	.1323
		(.0989)	(.0985)	(.0987)	(.0987)	(.1046)
Lnasset			−.6825***	−.6661***	−.6679***	−.6139***
			(.0476)	(.0504)	(.0504)	(.0563)
Lnkl				−.0178	−.0174	−.0296
				(.0175)	(.0175)	(.0237)
Lnage					.0466	.0102
					(.0602)	(.0647)
LEV						−.0715
						(.0664)
Provincepolicy						.2080***
						(.0654)
Year FE	Y	Y	Y	Y	Y	Y
Province FE	Y	Y	Y	Y	Y	Y
Industry FE	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y	Y
Constant	−5.3189***	−5.3187***	2.9096***	2.8047***	2.7559***	1.9781**
	(.3793)	(.3797)	(.6765)	(.6985)	(.6977)	(.8273)
Observations	61,890	61,890	61,886	61,404	61,403	40,053
R2	.7281	.7282	.7350	.7328	.7328	.7375

Notes: Robust standard errors for clustering to the firm level are in parenthesis. Year FE, indicates time fixed effects, Province FE, indicates Province fixed effects, Industry FE, indicates Industry fixed effects, and Firm FE, indicates Firm fixed effects. *, **, and *** indicate significant at the 10%, 5%, and 1% levels, respectively.

In order to analyze the channels through which export tax rebates affect firms' emission behavior, we examine the relevant mediating variables by drawing on the stepwise test proposed by Baron and Kenny (1986) (Baron RM and Kenny, 1986). The basic steps are as follows: (1) examine the relationship between the main independent variable and the dependent variable, and if the coefficient is significant, proceed to the next step, otherwise stop the test; (2) identify the correlation between the mediating variable and the dependent variable to see whether there is a statistically significant correlation; (3) The dependent variable is regressed on both the independent and mediating variables to test whether the regression coefficients of the mediating variables reach significance levels and whether the regression coefficients of the independent variables decrease. Based on Baron and Kenny's condition for the mediating effect to hold, the following three equations were developed.

$$lnSI_{ijkt} = a_1 * Retaxgap_i \times Post_t + a_2 * X_{it} + \gamma_i + \mu_j + \delta_k + \lambda_t + \varepsilon_{ijkt} \quad (2)$$

$$Channel_{ijkt} = b_1 * Retaxgap_i \times Post_t + b_2 * X_{it} + \gamma_i + \mu_j + \delta_k + \lambda_t + \varepsilon_{ijkt} \quad (3)$$

$$lnSI_{ijkt} = c_1 * Retaxgap_i \times Post_t + c_2 * Channel_{ijt} + c_3 * X_{it} + \gamma_i + \mu_j + \delta_k + \lambda_t + \varepsilon_{ijkt} \quad (4)$$

The mediating variables $Channel_{ijkt}$ include soot emissions, soot treatment, and coal use. X represents a series of control variables such as whether it is a state-owned enterprise, the size of the enterprise, and the age of the enterprise, which are the same as those in the previous section. According to Baron and Kenny (1986), if a_1, b_1 and c_2 are all significant, $Channel_{ijkt}$ plays a mediating role and the ratio of mediating utility to total utility can be expressed as $b_1 \times c_2/a_1$; if they are not all significant, the mediating effect may not exist.

4 Results

4.1 Baseline regression results

Table 2 reports the results of the baseline regressions on the effects of changes in export tax rebate policy on industrial

TABLE 4 Impact of export tax rebate rate reduction on the firms' soot emission intensity (Replace dependent variables).

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	Lnsootdensity1	Lnsootdensity1	Lnsootdensity1	Lnsootdensity1	Lnsootdensity1	Lnsootdensity1
$\text{Retaxgap}_i \times Post_t$	−.0215**	−.0219**	−.0196**	−.0184*	−.0184*	−.0196*
	(.0100)	(.0100)	(.0100)	(.0100)	(.0100)	(.0100)
Stateowned		.1447	.1419	.1445	.1440	.1430
		(.1028)	(.1027)	(.1031)	(.1031)	(.1031)
Lnasset			−.2905***	−.2685***	−.2692***	−.3516***
			(.0548)	(.0571)	(.0573)	(.0487)
Lnkl				−.0212	−.0211	−.0182
				(.0178)	(.0178)	(.0177)
Lnage					.0190	.0278
					(.0647)	(.0644)
LEV						−.1139
						(.0724)
Provincepolicy						.1098
						(.0686)
Year FE	Y	Y	Y	Y	Y	Y
Province FE	Y	Y	Y	Y	Y	Y
Industry FE	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y	Y
Constant	−2.0767***	−2.0770***	1.4279*	1.3073	1.2874	2.3274***
	(.4262)	(.4267)	(.7767)	(.7968)	(.7986)	(.7204)
Observations	61,932	61,932	61,927	61,268	61,267	61,248
R2	.6941	.6942	.6954	.6917	.6917	.6924

Notes: Robust standard errors for clustering to the firm level are in parenthesis. Year FE, indicates time fixed effects, Province FE, indicates Province fixed effects, Industry FE, indicates Industry fixed effects, and Firm FE, indicates Firm fixed effects. *, **, and *** indicate significant at the 10%, 5%, and 1% levels, respectively.

exporters' soot emission intensity. The regression results with the inclusion of time fixed effects, province fixed effects, industry fixed effects and firm fixed effects indicate that the reduction in export tax rebate rate has a significant negative impact on the intensity of soot emission intensity of industrial export enterprises, and the results remain robust after gradually adding control variables. The coefficient of the interaction term in column (6) indicates that for every 1-unit decrease in the average export tax rebate rate faced by industrial exporters, the firms' soot emission intensity decreases by 2.63%.

4.2 Robustness tests

4.2.1 Parallel trend test

The central premise of the validity of the DID model is that the parallel trend assumption is satisfied. Although the results in Table 2 show that the reduction in export tax rebate rate significantly reduces the smoke emission intensity of industrial exporters, endogeneity issues such as omitted variables, measurement errors and self-selection by firms cannot be completely excluded. In this paper, the parallel trend hypothesis is that if China does not adjust its export tax rebate policy, the trend of soot emission intensity of firms in the sample will be similar. We use event analysis to test this hypothesis. The equations are as follows:

$$lnSI_{ijkt} = \sum_{t=2005}^{2013} \beta_t * Retaxgap_i \times D_t + \beta_2 * X_{it} + \gamma_i + \mu_j + \delta_k + \lambda_t + \varepsilon_{ijkt} \quad (5)$$

Where D_t is the year dummy variable, β_t is the parameter to be focused on, and other variables have the same meaning as in (1). In this model, the year before the shock occurs, i.e., 2006, is set as the base year for the event analysis. Therefore, the specific meaning of the parameter β_t is whether there is a significant difference in the intensity of soot emissions of enterprises in the group with different export tax rebate rate changes in year t compared with 2006. The parallel trend hypothesis is satisfied if β_t is not significantly different from 0 before the adjustment of China's export tax rebate policy in 2007. Figure 1 plots the parameter β_t estimates and 95% confidence intervals. It can

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TABLE 5 Mediation mechanism of the effect of export tax rebate rate reduction on the firms' soot emission intensity.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Lnsootdischarge	Lncoal	Lnsoottreat	Lngovegasability	Lnsootdensity	Lnsootdensity	Lnsootdensity	Lnsootdensity
$Retaxgap_{ij} \times Post_t$	−.0221***	−.0036***	.0326**	.0133***	−.0051***	−.0103	−.0103	−.0261***
	(.0060)	(.0014)	(.0162)	(.0045)	(.0015)	(.0075)	(.0149)	(.0094)
Stateowned	.1971***	.0366	.1715	−.0158	−.0079	.0547	.4375**	.1714*
	(.0650)	(.0616)	(.2145)	(.1101)	(.0165)	(.0720)	(.2015)	(.0953)
Lnasset	−.0751***	.1244***	.4642***	.0201	−.5141***	−.5242***	−.3034***	−.6904***
	(.0279)	(.0330)	(.1194)	(.0569)	(.0071)	(.0444)	(.1079)	(.0561)
Lnkl	−.0401***	−.0276*	−.1234*	−.0029	.0257***	.0269	.0191	.0046
	(.0121)	(.0162)	(.0708)	(.0278)	(.0031)	(.0257)	(.0632)	(.0268)
Lnage	.1813***	.0915**	.0778	.1116*	−.1044***	−.0337	.3231***	.0958
	(.0368)	(.0373)	(.1216)	(.0649)	(.0094)	(.0459)	(.1101)	(.0597)
LEV	−.1355***	−.0659	−.1384	−.1398	.0932***	.1551*	.2495	−.0884
	(.0524)	(.0693)	(.2403)	(.1059)	(.0133)	(.0910)	(.2145)	(.0815)
Provincepolicy	.0986***	−.1474***	.0256	−.0128	.0538***	−.1546***	−.5495***	−.0070
	(.0381)	(.0395)	(.1419)	(.0666)	(.0097)	(.0515)	(.1297)	(.0624)
Lnsootdischarge					.9963***			
					(.0015)			
Lncoal						.0673***		
						(.0144)		
Lnsoottreat							.6752***	
							(.0270)	
Lngovegasability								.2076***
								(.0133)
Year FE	Y	Y	Y	Y	Y	Y	Y	Y
Province FE	Y	Y	Y	Y	Y	Y	Y	Y
Industry FE	Y	Y	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y	Y	Y	Y

(Continued on following page)

TABLE 5 (*Continued*) Mediation mechanism of the effect of export tax rebate rate reduction on the firms' soot emission intensity.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Lnsootdischarge	Lncoal	Lnsoottreat	Lngovegasability	Lnsootdensity	Lnsootdensity	Lnsootdensity	Lnsootdensity
Constant	6.0977***	4.6619***	−5.1505***	5.7829*	−5.9683***	−3.6912***	−2.0342	2.2156***
	(1.0891)	(1.0402)	(1.8349)	(3.0991)	(.2771)	(.8571)	(1.6172)	(.7837)
Observations	61,418	36,130	17,166	39,938	61,398	34,868	16,163	36,139
R2	.6854	.0321	.0533	.0993	.9819	.7501	.0406	.6365

Notes: Robust standard errors for clustering to the firm level are in parenthesis. Year FE, indicates time fixed effects, Province FE, indicates Province fixed effects, Industry FE, indicates Industry fixed effects, and Firm FE, indicates Firm fixed effects. *, **, and *** indicate significant at the 10%, 5%, and 1% levels, respectively.

be found that the DID model setting in this paper passes the parallel trend test.

4.2.2 Placebo test

Compared with 2006, in 2007, there were 4498 enterprises whose export tax rebate rates were reduced and 5582 enterprises whose export tax rebate rates did not change. Drawing on (Cai et al., 2016), this paper constructs placebo-tested pseudo-group dummy variables by randomly selecting 4498 firms from 10,380 respondents and setting them as a pseudo-treatment group for export tax rebate rate reduction, and setting the remaining 5882 respondents as a pseudo-control group. Pseudo-cross terms for the grouping dummy variable and the policy implementation time dummy variable are then constructed. Figure 2 reports the kernel densities of the estimated coefficients for the 500 pseudo-treatment groups and the corresponding p-value distributions. Where the x-axis indicates the magnitude of the estimated coefficients of Pseudo-cross terms, the y-axis indicates the magnitude of the density values and p-values, the curve is the kernel density distribution of the estimated coefficients, the blue dots are the p-values of the estimated coefficients, the vertical dashed line is the true estimate of the DID model -1.047, and the horizontal dashed line is the significance level .1. As can be seen from the figure, the estimated coefficients are mostly concentrated around the zero point, and the p-values of most of the estimated coefficients are greater than .1 (insignificant at the 10% level), further demonstrating that the study findings are robust.

4.2.3 Robustness test—Replacement of explanatory variables

In the baseline regression, the change in the company's export tax rebate rate is measured by the tax rate of the company's largest product. In the robustness test, the change in the company's export tax rebate rate of various products is multiplied by the proportion of sales of various products to total sales in 2006 to obtain the weighted average of the company's tax rate reduction, i.e., Retaxgap1. Table 3 shows that the regression results of adding time fixed effect, province fixed effect, industry fixed effect and company product fixed effect show that the reduction in export tax rebate rate has a significant negative impact on the company's smoke emission intensity. The results are still robust after gradually adding control variables. For every 1 unit decrease in the average export tax rebate rate faced by exports at the firm level, the industrial exporters' soot emission intensity decreases by 3.09%, which is basically consistent with the baseline regression results.

4.2.4 Robustness test—Replace the dependent variable

In the previous empirical analysis, the gross industrial output value of enterprises in the formula for calculating the soot emission intensity of enterprises was obtained from the industrial enterprise database. A related concern is that there may be a difference between the gross industrial output value of enterprises in the industrial enterprise database and the pollution database, and this difference may lead to a change in the main empirical findings. In fact, the comparison reveals that the gross industrial output values in the two databases are not exactly the same. To ensure the robustness of the study results, this section uses the gross

TABLE 6 Effect of lower export tax rebate rate on the intensity of soot emissions from SOEs and non-SOEs.

Variables	SOEs			Non-SOEs		
	Lnsootdensity	Lnsootdensity	Lnsootdensity	Lnsootdensity	Lnsootdensity	Lnsootdensity
$Retaxgap_{ij} \times Post_t$	−.0463*	−.0473*	−.0474*	−.0350***	−.0274**	−.0281***
	(.0272)	(.0273)	(.0270)	(.0110)	(.0107)	(.0107)
Lnasset		−.2761**	−.2823**		−.7040***	−.6296***
		(.1352)	(.1362)		(.0521)	(.0497)
Lnkl		.0509	.0458		−.0269	−.0306*
		(.0592)	(.0625)		(.0182)	(.0181)
Lnage			.1659			−.0120
			(.1187)			(.0725)
LEV			−.0401			−.0086
			(.0945)			(.0840)
Provincepolicy			−.0055			.1516**
			(.1641)			(.0732)
Year FE	Y	Y	Y	Y	Y	Y
Province FE	Y	Y	Y	Y	Y	Y
Industry FE	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y	Y
Constant	−6.3105***	−2.7223	−3.0519	−3.4752***	4.4387***	3.6844***
	(.7712)	(1.9047)	(1.9686)	(.3409)	(.7085)	(.6866)
Observations	7301	7242	7237	54,589	54,162	54,147
R2	.7550	.7526	.7529	.7273	.7333	.7327

Notes: Robust standard errors for clustering to the firm level are in parenthesis. Year FE, indicates time fixed effects, Province FE, indicates Province fixed effects, Industry FE, indicates Industry fixed effects, and Firm FE, indicates Firm fixed effects. *, **, and *** indicate significant at the 10%, 5%, and 1% levels, respectively.

industrial output value of enterprises in the enterprise pollution database to calculate the intensity of enterprise soot emissions, and the corresponding regression results are reported in Table 4. It can be seen that the reduction of export tax rebate rate has a significant negative effect on enterprise soot emission intensity, and the two ways of calculating enterprise soot emission intensity lead to basically the same conclusion.

4.3 Mechanism analysis

In Section 3, we find that a reduction in the export tax rebate rate has a significant negative impact on the intensity of smoke emissions from firms. In this section, we further explore how export tax rebate rate reduction reduces soot emissions intensity. The mechanism test is to investigate whether the export tax rebate rate can reduce enterprise soot emission intensity through the reduction of emissions and the increase of pollution treatment. The empirical results are shown in Table 5.

The coefficients of the interaction terms in columns (1), (2), (3) and (4) of Table 5 indicate that the reduction in the export tax rebate rate leads to a decrease in the amount of soot generated and the amount of coal used by firms, an increase in the amount of soot treated and the amount of soot treated per hour. Columns (5), (6), (7) and (8) report the results with the inclusion of mediating variables, where the values of the coefficients of the interaction terms decrease or are no longer statistically significant, and the coefficients of the mediating variables are significantly positive, indicating that lnsootdischarge, lncoal, lnsoottreat and Lngovegasability are the mediating mechanisms by which the reduction in the export tax rebate rate affects firms' soot emission intensity.

4.4 Results of the heterogeneity analysis

The heterogeneity estimation results of the impact of export tax rebate rate reduction on soot emission intensity of different types of enterprises are shown in Table 6. Negative results for all interaction terms in each column imply that both state-owned enterprises (SOEs) and non-state-owned enterprises (non-SOEs) reduce their soot emission intensity when the export tax rebate rate is reduced. Specifically, for every 1-unit decrease in the average real export tax rebate rate of enterprises, the soot emission intensity from SOEs decreased by 4.74% and soot emissions from non-SOEs decreased by 2.81%.

TABLE 7 Effect of lower export tax rebate rate on the intensity of soot emissions from HHR industries and non-HHR industries.

Variables	HHR industries			Non-HHR industries		
	Lnsootdensity	Lnsootdensity	Lnsootdensity	Lnsootdensity	Lnsootdensity	Lnsootdensity
$Retaxgap_{ij} \times Post_t$	−.0286**	−.0221**	−.0216**	−.0260*	−.0231	−.0235
	(.0112)	(.0109)	(.0109)	(.0148)	(.0146)	(.0146)
Stateowned		.1845*	.1901*		.2925***	.2870**
		(.0978)	(.0977)		(.1132)	(.1130)
Lnasset		−.6097***	−.5782***		−.6584***	−.5866***
		(.0576)	(.0497)		(.0520)	(.0526)
Lnkl		−.0122	−.0143		.0016	−.0019
		(.0173)	(.0172)		(.0216)	(.0215)
Lnage			.0514			.1612**
			(.0643)			(.0732)
LEV			−.0736			−.1816**
			(.0658)			(.0874)
Provincepolicy			.1499**			.2559***
			(.0684)			(.0732)
Year FE	Y	Y	Y	Y	Y	Y
Province FE	Y	Y	Y	Y	Y	Y
Industry FE	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y	Y
Constant	−5.1577***	2.3042**	1.9170**	−6.2907***	1.6982*	.7821
	(.6081)	(.9260)	(.8640)	(.6947)	(.9220)	(.9340)
Observations	46,447	46,039	46,023	42,723	42,444	42,433
R2	.7096	.7120	.7121	.6859	.6913	.6915

Notes: Robust standard errors for clustering to the firm level are in parenthesis. Year FE, indicates time fixed effects, Province FE, indicates Province fixed effects, Industry FE, indicates Industry fixed effects, and Firm FE, indicates Firm fixed effects. *, **, and *** indicate significant at the 10%, 5%, and 1% levels, respectively.

The regression results of the heterogeneity analysis by industry are presented in Table 7. The reduction of export tax rebate rate significantly reduces the soot emissions of highly polluting, energy-consuming and resource-based (HHR) industries, and has no significant effect on the soot emissions of non-HHR industries. Specifically, for every 1-unit decrease in the average real export tax rebate rate of enterprises, the soot emission intensity from HHR industries decreased by 2.16%.

5 Discussion

Many previous studies suggest that export tax rebate policy, which are important policy tools for governments, are often used to stimulate export (Chong'En et al., 2011; Lee et al., 2021) and firm productivity (Zhang, 2019), thereby promoting economic growth (Xu, 2018). Few studies have explored the impact of the export tax rebate policy adjustment that may lead to environmental improvements. In this paper, we systematically explore the environmental effects of the export tax rebate rate reduction policy using three large representative micro data sets in China. We find that the reduction in the export tax rebate rate significantly reduces the intensity of corporate soot emissions, and this finding holds after a series of robustness tests. For every 1-unit reduction in export tax rebate rate, enterprises' soot emission intensity decreases by 2.63%. Our results are basically consistent with the previous literature. Song et al. (2015) examined the relationship between export tax rebates and pollution emissions in China using a computable general equilibrium model, and found that China's export tax rebates reduce support for highly polluting export industries and thus led to a reduction in emissions. Fan et al. (2015) used the CEEPA (China Energy and Environmental Policy Analysis system) model to simulate the impact and socioeconomic consequences of eliminating export tax rebates on CO2 emissions. They concluded that the current policy of eliminating export tax rebates for key industries could promote emission reduction, but would have a negative impact on the economy. In contrast to the lack of firm-level analysis of environmental behavior in existing studies, this paper empirically investigates the impact of export tax rebate policy on industrial exporters' soot emissions, making a marginal contribution to the existing research on the environmental effects of export tax rebate policy.

The mechanism analysis shows that the reduction of emissions and the increase of pollution treatment are important channels. Specifically, we find that export tax rebates reduce the amount of coal used by firms. As a large energy consumer, heavy industrial polluting enterprises in China consume a lot of coal and most of the soot emissions are caused by coal use (Wang et al., 2018; Mengshu et al., 2021; Heerma Van Voss and Rafaty, 2022; Li et al., 2022; Zhao et al., 2023). The reduction in coal use means that from the enterprise level, the reduction of export tax rebate rate will force enterprises to optimize their energy structure, thus alleviating the problem of high percentage of coal use by Chinese industrial enterprises. Our analysis is supported to some extent by the research of Wang and Liang, who argue that the development of environmental regulations in China could further improve energy efficiency and carbon neutrality (Wang and Liang, 2022). In addition, we find that the export rebate enhances the efficiency of soot treatment. The possible reason is that companies increase their investment in environmental equipment or green technology innovation stimulated by the tax policy (Li and Li, 2022; Wang Z et al., 2022).

Heterogeneity analysis shows that the reduction of export tax rebate rate has a more significant impact on the intensity of soot emissions of high pollution, high energy consumption and resource-based enterprises. The main reason is that the adjustment of export tax rebate policy in 2007 is mainly aimed at curbing the development of high pollution, high energy consumption and resource-based industries (Lee et al., 2021). Specifically, the export tax rebate rate for chemical products, some chemicals, some steel and base metals and other products dropped by 11.1% on average (Song et al., 2015).

Our study also has certain limitations. On the one hand, limited by the indicators of the data, we do not have the means to assess all aspects of the changes in export tax rebate policies on firms' micro-pollution behavior. On the other hand, this study involves a large amount of data on traded products and their corresponding export tax rebate rates. Using the change in export tax rebate rates calculated by the largest traded products of the company and the change in export tax rebate rates calculated by the weighted average of the company's product shares, the impact of the policy may be somewhat underestimated due to the company's initiative to adjust its product mix in the face of the reduction in product export tax rebate rates.

6 Conclusion

Using the China Industrial Enterprise Database, China Industrial Enterprise Pollution Database and China Customs Import and Export Database for 2005–2013, DID estimations show that for every 1-unit reduction in export tax rebate rate, soot emission intensity of industrial export enterprises decreases by 2.63%. The reduction in soot generation, the reduction in coal use intensity, the increase in total amount and efficiency of soot treatment are four important channels through which the export tax rebate rate affects the emission behavior of enterprises.

The policy implication of this study is that reducing export tax rebate rates for export products, especially for high pollution, high energy-consuming and resource-based industries, is a favorable policy option to improve China's environmental performance in international trade. This study may provide a reference for other developing countries that also rely on export tax rebates to adjust their policies to combine economic growth with pollution control.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: 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

Conceptualization, YZ; Methodology, QT and AH; Software, QT, AH, and YZ; Validation, QT, YZ, and YM; Formal analysis, QT and AH; Writing—original draft preparation, QT, AH, and YZ; Writing—review and editing, QT, AH, and YZ; Visualization, QT, YZ, and YM; Supervision, YZ; Project administration, YZ and YM; Funding acquisition, YZ.

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Conflict of interest

YM was empolyed by the Offshore Oil Engineering Co., Ltd.

The remaining 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.

Publisher's note

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Can ESG investments and new environmental law improve social happiness in China?

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Air pollution was a serious issue in China in the early 2010s, threatening public health and sustainable economic development. The Chinese government established a new environmental protection law in 2015 in order to address air pollution and other environmental issues. This paper investigates the impact of the new environmental law and ESG investments on air pollution and social happiness. We discovered that the implementation of the new environmental law and ESG investments significantly improved social happiness by reducing air pollution. One unit increase in ESG investments would result in a 0.334 unit decrease in air pollution and 0.225 unit increase in social happiness.

KEYWORDS

social happiness, environmental law, sustainable development, ESG investment, air pollution

1 Introduction

With the rapid development of the economy, productivity has increased significantly, while environmental pollution has increased, resulting in a slew of environmental issues that have serious implications for public health and the sustainable development of society. Environmental protection was first introduced as a clear scientific concept in 1972 at the United Nations Conference on the Human Environment. Since then, countries all over the world have gradually improved their environmental laws. According to the Declaration on the Human Environment, "peace, development, and environmental protection are interdependent and inseparable." The primary goals of environmental management include promoting sustainable development and ensuring the happiness of citizens.

The relationship between happiness and the environment has received increased research attention in recent years (Krekel and MacKerron, 2020; Maddison et al., 2020; Bonasia et al., 2022). Traditional economic indicators of wellbeing are poor predictors of happiness. Welfare policies that place a greater emphasis on happiness can help to achieve the goals of environmental and social sustainability (Gowdy, 2005). Air pollution is a major environmental issue in many countries. Menz (2011) examined data sets from 48 countries from 1990 to 2006 and discovered that people are not accustomed to particulate pollution. Even previous pollution levels can reduce current utility. Solving environmental issues and maintaining ecological balance are critical to people's happiness. Welsch (2006) investigates the relationship between air quality and happiness using panel data on self-reported happiness from ten European countries. He discovered that air pollution is a statistically significant predictor of inter-country and inter-temporal differences in subjective happiness, and that the effect of air pollution on happiness translates into a significant monetary value of improved air quality. These concerns about environmental quality and its impact on people's welfare are fundamental arguments for most countries' adoption of environmental legislation. Air quality is linked to subjective happiness in Europe, with sulfur dioxide concentrations having a significant negative impact on self-reported life satisfaction (Ferreira et al., 2013). In the United States, air pollution has a direct impact on people's happiness, as well as any measured effects through health, lost work days, and other observable outcomes (Levinson, 2012). Breslow et al. (2016) developed an integrated framework about environmental conditions and management actions in response to growing interest in assessing the impact of changing environmental conditions and management actions on happiness. They contend that happiness cannot be a secondary goal of environmental policy. The possible link between environmental policy and happiness is something that needs to be looked into further. Public support for environmental protection is a reaction to the decline in quality of life caused by overexploitation of natural resources, and it seeks to restore happiness by improving environmental quality and ensuring a healthy ecosystem. Thus, public support serves to provide environmental protection and pollution reduction, which can be considered wellbeing attributes because they influence individuals' and communities' ability to achieve healthy environmental goals. Empirically, Bonasia et al. (2022) examine micro and macro data from 19 European countries from 1997 to 2019 and discover a direct link between happiness and long-term environmental protection spending in European countries. They advocate for governments to include environmental spending as a means of increasing domestic happiness, emphasizing the importance of the interaction between environmental quality and life satisfaction.

Environmental pollution in developing countries has become a global issue since the twenty-first century. Air pollution has caused serious health problems in China and India since 2010. According to the World Health Organization (2016), China and India had the highest number of air pollution-related deaths in 2012. Environmental pollution's threats to life and health severely reduce people's happiness (Huhtala and Samakovlis, 2007; Almetwally et al., 2020). Air pollution can have an impact on both physical and psychological health. Shi and Yu (2020) use the number of environmental regulations at the prefecture level to assess the welfare loss caused by air pollution. Their findings suggest a link between air pollution and individual happiness. The impact of PM2.5 emissions on happiness is more closely related to physical health than mental health. According to some studies, pollution can cause significant decreases in happiness (Chen et al., 2013; Ebenstein et al., 2017). Environmental regulations are classified into three types, according to Guo et al. (2020). (i.e., economic environmental regulation, legal environmental regulation, and supervised environmental regulation). They conducted an econometric analysis on the relationship between environmental regulations and happiness, and examined the time-lag effect of policy implementation, using micro data from the Chinese Social Census and macro data from 28 Chinese provinces and cities from 2013 to 2015. They demonstrate that long-term economic and environmental regulation can significantly improve happiness. The Chinese government has enacted environmental regulations that require cities to report their daily air quality data. This mandatory disclosure of air quality information regulation has had a significant positive impact on individual happiness, primarily by lowering air pollution (Wang et al., 2021). According to Tian et al. (2016), environmental information disclosure is effective in pollution control. In China, public information requests may be the most effective method of pollution control. According to Xu et al. (2022), all three types of environmental regulations (command-and-control, market-based, and voluntary) can reduce the negative effects of air pollution on residents' happiness, but the overall mitigation effect is non-linear. In terms of welfare, air pollution is costly to society and individuals. Some studies examine the effects of environmental pollution on social welfare (Smyth et al., 2008; Smyth et al., 2011; Li and Zhou, 2020; Wang et al., 2020; Yang et al., 2020), whereas the effects of environmental policies on social welfare require further investigation.

In the early 2010s, China's air pollution reached crisis proportions. To protect public health, the Chinese government proposed the Action Plan for Air Pollution Prevention and Control (APAPCC) in 2013 and reformed environmental protection legislation. The new environmental protection law was approved on 24 April 2014, and went into effect in early 2015. Since the old law was passed in 1989, this was the first time the Chinese government amended the law to address the new era's environmental pollution problem. The new law emphasizes "public participation" and "liability for damage" (Liu et al., 2021.). It makes significant changes in the following areas. First, environmental protection and public welfare organizations can file environmental public interest litigation against polluting enterprises that commit illegal and environmentally destructive acts. Second, it increases government and official accountability and power. The new law states unequivocally that the government is responsible for environmental quality within its administrative jurisdiction. The ecological protection red line is an important standard for assessing government officials' environmental protection responsibilities during their tenure. Local environmental agencies have the authority to halt illegal environmental activities. Furthermore, it significantly increases polluters' responsibility. High-polluting businesses must provide more specific environmental information to the public, such as the name of pollutants discharged, emission method, emission concentration and emission level, total emissions of major pollutants and excessive emissions, and details on the construction and operation of pollution prevention facilities. Furthermore, the law establishes a daily penalty system, which means that businesses involved in pollution cases will be fined indefinitely until they correct illegal pollutant discharge behavior.

Recently, ESG investment has been widely recognized as an effective means of protecting the environment and ensuring the economy's long-term development, attracting significant research attention. According to Li and Li (2022), an environmental protection tax implemented in China in 2018 significantly improved ESG investments by Chinese listed companies and promoted green technological innovations. They also established a link between ESG performance and green innovation. Zheng et al. (2022) discover a long-run bidirectional comovement between ESG performance and enterprise green innovation output. According to Bada et al. (2019), high-rated government bonds outperform low-rated bonds across all ESG dimensions. Zhou and Zhou (2021) showed that good ESG performance reduced the increase in stock price volatility caused by COVID-19, and played a role in improving "resilience" and stabilizing stock prices. Since the emission of air pollutants by polluting industries is considered the major source of air pollution in China, ESG investments strength should be closely related to air pollution.

This paper examines how ESG investments and China's new environmental law affect social happiness. We collect the most recent environmental, macroeconomic, ESG investment, and social survey data and analyze the impact of ESG investments and new

TABLE 1 Definition of variables.

Abbreviation	Variables	Definition	Sources	Mean	Std	Obs
HAP	Happiness	Provincial happiness level calculated by averaging personal happiness score in each province every year	CGSS, CFPS, CSS	3.89	0.19	135
ESG	ESG score	Environmental, Social and Governance aggregate investment score	SynTao Green Finance	10.52	15.87	135
ENV	Environmental score	Environmental investment score		11.53	17.26	135
SOC	Social score	Social investment score		9.62	14.67	135
GOV	Governance score	Corporate governance investment score		10.37	15.68	135
AQI	Air Quality Index	The level of air pollution	China Air Quality Online Detection and Analysis Platform	79.42	20.10	135
PM2.5	Particulate Matter 2.5	Particulate matters that have a diameter less than 2.5 μm		48.51	15.37	135
PM10	Particulate Matter 10	Particulate matters that have a diameter less than 10 μm		85.61	29.11	135
IAV	Industrial added value	The gross output value of industrial enterprises minus the purchase of raw materials	the National Bureau of Statistics of China	12869.08	9791.1	135
PD	Population density	Density of population(person/sq.km)		2927.54	1144.94	135
AA	Afforestation area	In all the land that can be planted, trees and shrubs are planted by various methods, and the survival rate reaches 85% or more(hectare)		35.21	16.69	135
C	Coal	Coal consumption by region (10 thousand tons)		15556.12	12084.25	135
MDE	Medical expenditure	Public financial expenditure of local government-Medical treatment and public health (100 million yuan)		503.88	253.97	135
EDE	Educational expenditure	Public financial expenditure of local government-Education (100 million yuan)		1012.34	537.65	135
EC	Education construction	Completion of capital construction investment in the education sector-Total investment completed in the current year (10 thousand yuan)		1376045	1044824	135
POP	Population	Total population at year end		5008.26	2801.32	135
SO_2	Sulfur dioxide	Sulfur dioxide emission of waste gas (10 thousand tons)		30.01	26.66	135
UEI	Urban environment infrastructure	Investment in urban environment infrastructure by region (100 million yuan)		202.02	140.629	135
UR	Unemployment rate	Ratio of the unemployed to the working population (%)		3.23	0.622	135
GDP	GDP per Capita	Total output divided by total population		59694.05	29139.38	135
DR	Divorce rate	Number of divorces per 1,000 people (‰)		2.95	0.98	135
PUP	Proportion of urban population	Ratio of urban population to total population (%)		61.72	11.40	135
BR	Birth rate	Rate of average number of births per 1,000 people (‰)		10.91	2.68	135
DER	Death rate	Rate of average number of deaths per 1,000 people (‰)		6.22	0.78	135

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TABLE 2 Impact of air pollution on social happiness at provincial level.

Dependent variable: Happiness						
—	(1)	(2)	(3)	(4)	(5)	(6)
AQI	− 0.674**	—	—	− 1.068**	—	—
	(− 2.66)	—	—	(− 2.44)	—	—
PM2.5	—	− 0.686**	—	—	− 1.203**	—
	—	(− 2.24)	—	—	(− 2.2)	—
PM10	—	—	− 0.414***	—	—	− 0.434
	—	—	(− 2.81)	—	—	(− 1.39)
Lag.HAP	—	—	—	9.076	12.112	5.613
	—	—	—	(0.5)	(0.65)	(0.31)
C	1.50E − 03	1.61E − 03	1.51E − 03	3.3E − 06	9.89E − 04	6.42E − 04
	(1.00)	(0.94)	(1.02)	(0.15)	(0.45)	(0.3)
MDE	0.027	0.026	0.032	0.010	− 0.039	0.006
	(0.42)	(0.41)	(0.51)	(0.08)	(− 0.28)	(0.05)
EDE	− 0.057	− 0.055	− 0.045	− 0.031	0.004	− 0.010
	(− 1.50)	(− 1.46)	(− 1.20)	(− 0.4)	(− 0.05)	(− 0.12)
EC	− 2.08E − 06	− 1.73E-06	− 2.37E − 06	5.71E − 06	6.06E − 06	5.96E − 06
	(− 0.55)	(− 0.47)	(− 0.62)	(0.99)	(1.02)	(1.01)
POP	0.073**	0.073*	0.058*	0.011	− 4.09E − 03	− 0.015
	(2.10)	(2.04)	(1.79)	(0.16)	(− 0.06)	(− 0.22)
SO_2	0.086	0.118	0.099	0.135	0.313	0.220
	(0.93)	(1.16)	(1.09)	(0.29)	(0.66)	(0.47)
UEI	− 0.029	− 0.030	− 0.025	− 0.018	− 0.022	− 0.022
	(− 1.11)	(− 1.12)	(− 1.01)	(− 0.32)	(− 0.39)	(− 0.4)
UR	− 2.480	− 2.396	− 2.412	− 5.299	− 6.701	− 4.627
	(− 0.44)	(− 0.41)	(− 0.42)	(− 0.54)	(− 0.66)	(− 0.46)
GDP	− 4.12E − 05	− 5.92E − 05	− 4.16E − 05	− 2.23E − 05	− 4.76E − 05	2.21E − 05
	(− 0.42)	(− 0.58)	(− 0.43)	(− 0.17)	(− 0.35)	(0.17)
DR	− 3.435*	− 3.729*	− 3.827*	− 3.639	− 3.891	− 3.964
	(− 1.73)	(− 1.71)	(− 1.95)	(− 1.16)	(− 1.21)	(− 1.26)
PUP	1.753	1.931*	1.568	0.751	0.978	1.536
	(1.66)	(1.77)	(1.38)	(0.29)	(0.37)	(0.58)
BR	−5.738***	− 5.785***	− 5.266***	− 1.792	− 1.328	− 2.404
	(− 3.51)	(− 3.71)	(− 3.28)	(− 0.55)	(− 0.38)	(− 0.73)
DER	− 3.526	− 2.184	− 0.901	− 10.991	− 10.703	− 9.785
	(− 0.45)	(− 0.28)	(− 0.12)	(− 0.95)	(− 0.9)	(− 0.84)
Adj. R square	0.314	0.300	0.295	—	—	—

Values in parentheses are t-values. *, **, and *** represent for significance at 10%, 5%, and 1%, respectively. AQI, PM2.5, and PM10 refer to Air Quality Index, Particulate Matter 2.5, and Particulate Matter 10. Definitions of other control variables are provided in Table 1.

environmental legislation on social happiness. We contribute to the literatures as follows. First, while the impact of ESG investment on social welfare would be of great research interest, such issues have not been adequately studied. We fill this void by emphasizing the importance of ESG investment's social impact. Second, literature on happiness focuses primarily on the individual level. We

TABLE 3 Impact of ESG investments and the implementation of new environmental protection law on air quality index.

Dependent variable: AQI								
—	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ESG	− 0.334***	—	—	—	− 0.328***	—	—	—
	(− 4.36)	—	—	—	(− 4.38)	—	—	—
ENV	—	− 0.339***	—	—	—	− 0.333***	—	—
	—	(− 4.31)	—	—	—	(− 4.35)	—	—
SOC	—	—	− 0.308***	—	—	—	− 0.303***	—
	—	—	(− 4.37)	—	—	—	(− 4.39)	—
GOV	—	—	—	− 0.360***	—	—	—	− 0.353***
	—	—	—	(− 4.39)	—	—	—	(− 4.39)
NEL	—	—	—	—	− 7.974***	− 8.005***	− 7.963***	− 7.952***
	—	—	—	—	(− 3.3)	(− 3.31)	(− 3.29)	(− 3.29)
UEI	− 1.80E − 03	− 1.91E − 03	− 1.73E − 03	− 1.85E − 03	0.017	0.017	0.017	0.017
	(− 0.14)	(− 0.15)	(− 0.14)	(− 0.15)	(1.33)	(1.32)	(1.33)	(1.32)
AA	− 0.762***	− 0.763***	− 0.763***	− 0.759***	− 0.752***	− 0.753***	− 0.753***	− 0.749***
	(− 4.85)	(− 4.86)	(− 4.86)	(− 4.82)	(− 5.46)	(− 5.47)	(− 5.47)	(− 5.43)
PD	− 2.86E − 04	− 3.07E − 04	− 2.8E − 04	− 3.01E − 04	7.63E − 04	7.49E − 04	7.68E − 04	7.46E − 04
	(− 0.17)	(− 0.18)	(− 0.16)	(− 0.17)	(0.47)	0.46	(0.48)	(0.46)
IAV	2.82E − 04	2.88E − 04	2.88E − 04	2.80E − 04	1.73E − 04	1.71E − 04	1.78E − 04	1.69E − 04
	(1.02)	(1.01)	(1.04)	(1.01)	(0.69)	0.68	(0.71)	(0.68)
Adj.R square	0.297	0.294	0.297	0.299	0.427	0.425	0.427	0.429

Values in parentheses are t-values. *, **, and *** represent for significance at 10%, 5%, and 1%, respectively. ESG, ENV, SOC, GOV, and NEL, represent for ESG, investment, environmental investment, social investment, corporate governance investment and the treatment effect of new environmental protection law, respectively. Definitions of other control variables are provided in Table 1.

approach our analysis in this paper from a macro perspective. As a result, our findings are critical for policymakers.

According to our findings, China's air pollution has significantly reduced social happiness. ESG investments and the new environmental law significantly reduced air pollution, restoring severely damaged social happiness in the years that followed.

The remainder of the paper is organized as follows. Section 2 briefly describes our data. Our models are introduced in Section 3. Section 4 discusses the empirical findings, and Section 5 concludes.

2 Data

We focus on the impact of air pollution, ESG investment, and new environmental law on social happiness in this paper. Our sample spans the years 2015–2019. We obtain the most recent personal happiness score from the Chinese General Social Survey (CGSS), the China Family Panel Studies (CFPS), and the Chinese Social Survey (CSS). We use all of these data to build our social happiness data because these social surveys were not conducted every year. Specifically, we use CGSS 2015, 2017, and 2018, CFPS 2016, and CSS 2019. Then, each year, we calculate the provincial happiness score as the average of personal happiness in each province. We unified the scale of these data because the CFPS's scale of happiness score (which ranges from one to ten) differs from the CGSS's and CSS's (which range from one to five).

Our ESG data, which includes environmental, social and corporate governance investment scores on China's listed companies, is provided by Syntao Green Finance in China. These scores are rated according to 14 categories and over 200 indicators. The aggregate ESG investment strength is a better indicator of local environmental protection efforts than the average ESG investment level of listed businesses, thus we calculate the ESG and environmental investment scores at the provincial level by adding up these scores in each province.

We obtain information on the air quality index (AQI), PM2.5, and PM10 from the China Air Quality Online Detection and Analysis Platform in terms of air pollution. The average of the cities within each province is used to calculate the air quality data at the provincial level.

Other control variables are gathered from the National Bureau of Statistics of China and include industrial added value, population density, afforestation area, coal consumption, government medical and educational spending, unemployment rate, GDP *per capita*, divorce rate, proportion of urban population, birth rate, and death rate, among others. Table 1 lists the definitions of the variables and the summary statistics.

TABLE 4 Impact of ESG investments and the implementation of new environmental protection law on PM2.5

Dependent variable: PM2.5								
—	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ESG	− 0.302***	—	—	—	− 0.296***	—	—	—
	(− 4.26)	—	—	—	(− 4.28)	—	—	—
ENV	—	− 0.305***	—	—	—	− 0.300***	—	—
	—	(− 4.19)	—	—	—	(− 4.23)	—	—
SOC	—	—	− 0.279***	—	—	—	− 0.273***	—
	—	—	(− 4.27)	—	—	—	(− 4.29)	—
GOV	—	—	—	− 0.327***	—	—	—	− 0.319***
	—	—	—	(− 4.30)	—	—	—	(− 4.30)
NEL	—	—	—	—	− 7.741***	− 7.772***	− 7.735***	− 7.710***
	—	—	—	—	(− 3.45)	(− 3.45)	(− 3.44)	(− 3.43)
UEI	− 4.92E − 03	− 5.07E − 03	− 4.85E − 03	− 4.87E − 03	0.015	0.015	0.015	0.015
	(− 0.42)	(− 0.44)	(− 0.42)	(− 0.42)	(1.31)	(1.30)	(1.31)	(1.31)
AA	− 0.496***	− 0.497***	− 0.497***	− 0.493***	− 0.483***	− 0.484***	− 0.484***	− 0.481***
	(− 3.76)	(− 3.77)	(− 3.77)	(− 3.74)	(− 4.33)	(− 4.34)	(− 4.34)	(− 4.31)
PD	− 1.32E − 05	− 3.42E − 05	− 7.48E − 06	− 2.08E − 05	1.06E − 03	1.05E − 03	1.07E − 03	1.05E − 03
	(− 0.01)	(− 0.02)	(− 0.00)	(− 0.01)	(0.76)	(0.75)	(0.77)	(0.76)
IAV	2.62E − 04	2.59E − 04	2.68E − 04	2.61E − 04	1.57E − 04	1.56E − 04	1.62E − 04	1.54E − 04
	(1.10)	(1.09)	(1.13)	(1.10)	(0.76)	(0.75)	(0.78)	(0.74)
Adj.R square	0.280	0.277	0.280	0.282	0.443	0.441	0.443	0.445

Values in parentheses are t-values. *, **, and *** represent for significance at 10%, 5%, and 1%, respectively. ESG, ENV, SOC, GOV, and NEL, represent for ESG, investment, environmental investment, social investment, corporate governance investment and the treatment effect of new environmental protection law, respectively. Definitions of other control variables are provided in Table 1.

3 Models

First, we construct the following panel regression model to investigate the impact of air pollution on social happiness.

$$HAP_{i,t} = \alpha_0 + \alpha_1 AIR_{i,t} + \mathbf{X\beta} + \varepsilon_{i,t} \tag{1}$$

where $HAP_{i,t}$ represents for social happiness level in province i in year t. AIR refers to air pollution, which is represented by AQI, PM2.5 and PM10. $\mathbf{X}$ represents the vector of control variables. $\varepsilon_{i,t}$ is the error term. According to Bonasia et al. (2022) and Xu et al. (2022), coal consumption, government medical expenditure, government educational expenditure, education construction, population, SO_2 emission, urban environment infrastructure, unemployment rate, divorce rate, gross domestic product, proportion of urban population, birth rate, and death rate are selected as control variables.

Then, we construct the following Difference-in-Difference models to examine the influence of ESG investment and the implementation of new environmental law on air pollution.

$$AIR_{i,t} = \alpha_0 + \alpha_1 ESG_{i,t} + \alpha_2 NEL + \mathbf{X\beta} + \varepsilon_{i,t} \tag{2}$$

where $AIR_{i,t}$ is the air pollution level. $NEL = Treat_i \times Post_t$ represents for the influence of implementation of new environmental law on air pollution. $Treat_i$ equals one if the air was heavily polluted in province i in 2015 (in our sample, the annual average AQI was larger than 90), and equals 0 otherwise. $Post_t$ equals 1 after 2016 and equals 0 otherwise. We put it in this manner since these social surveys were carried out every year at the midterm. In particular, the CGSS 2015 was conducted in June 2015, just 6 months after the new environmental law went into effect. Since the time-lag effect of environmental policy implementation has been demonstrated by Guo et al. (2020), we postpone the treatment effect of the new environmental law to 2016. After that, we may evaluate if ESG investments and the new environmental regulation are effective at reducing severe air pollution. The vector of control variables is represented by **X.** According to Borck and Schrauth (2021), Yuan et al. (2018), and Yao et al. (2020), the control variables chosen include afforestation area, urban environment infrastructure, population density, and industrial added value.

4 Empirical results

In this part, we first investigate whether, from a global perspective, air pollution has an impact on social happiness. The impact of ESG investments and the enforcement of new environmental protection laws on air pollution is then examined.

TABLE 5 Impact of ESG investments and the implementation of new environmental protection law on PM10.

Dependent variable: PM10								
—	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ESG	− 0.392***	—	—	—	− 0.369***	—	—	—
	(− 3.66)	—	—	—	(− 3.64)	—	—	—
ENV	—	− 0.396***	—	—	—	− 0.375***	—	—
	—	(− 3.61)	—	—	—	(− 3.61)	—	—
SOC	—	—	− 0.362***	—	—	—	− 0.341***	—
	—	—	(− 3.67)	—	—	—	(− 3.65)	—
GOV	—	—	—	− 0.420***	—	—	—	− 0.394***
	—	—	—	(− 3.66)	—	—	—	(− 3.63)
NEL	—	—	—	—	− 13.039***	− 13.071***	− 13.020***	− 13.030***
	—	—	—	—	(− 4.04)	(− 4.04)	(− 4.03)	(− 4.04)
UEI	− 9.18E − 03	− 9.32E − 03	− 9.04E − 03	− 9.34E − 03	0.011	0.011	0.011	0.011
	(− 0.52)	(− 0.52)	(− 0.51)	(− 0.53)	(0.64)	(0.63)	(0.64)	(0.63)
AA	− 1.109***	− 1.110***	− 1.109***	− 1.106***	− 1.128***	− 1.130***	− 1.129***	− 1.126***
	(− 4.78)	(− 4.8)	(− 4.79)	(− 4.75)	(− 5.12)	(− 5.14)	(− 5.13)	(− 5.09)
PD	− 1.85E − 03	− 1.86E − 03	− 1.83E − 03	− 1.88E − 03	− 8.74E − 04	− 8.89E − 04	− 8.63E − 04	− 9.09E − 04
	(− 0.75)	(− 0.76)	(− 0.75)	(− 0.76)	(− 0.37)	(− 0.38)	(− 0.37)	(− 0.39)
IAV	3.03E − 04	2.99E − 04	3.13E − 04	2.98E − 04	1.73E − 04	1.70E − 04	1.81E − 04	1.67E − 04
	(0.75)	(0.74)	(0.78)	(0.74)	(0.45)	(0.44)	(0.47)	(0.43)
Adj.R square	0.257	0.255	0.257	0.259	0.414	0.412	0.412	0.416

Values in parentheses are t-values. *, **, and *** represent for significance at 10%, 5%, and 1%, respectively. ESG, ENV, SOC, GOV, and NEL, represent for ESG, investment, environmental investment, social investment, corporate governance investment and the treatment effect of new environmental protection law, respectively. Definitions of other control variables are provided in Table 1.

The empirical results of Equation 1 are reported in Table 2. Clearly, case (1) demonstrates that, after controlling for other factors, the impact of air pollution on social happiness is statistically and economically significant at the provincial level. One unit drop in the AQI increases social happiness by 0.674 unit, showing that an improvement in the air quality immediately and significantly increased social happiness. In cases (2) and (3), PM2.5 and PM10, respectively, stand in for air pollution. Similar consequences to those in case (1) are visible to us. One may consider that social happiness may be affected by its previous period. Thus, we apply the dynamic panel approach, and these results are presented in case (4), (5), and (6). Similarly, the impact of air pollution on social happiness is still significant. These are in line with previous literatures (Welsch, 2006; Levinson, 2012; Ferreira et al., 2013; Breslow et al., 2016; Bonasia et al., 2022), which demonstrates the negative impact of air pollution on happiness in advanced economies.

The impact of ESG investments and the new environmental protection law on air pollution is then investigated. Table 3 displays the results of Equation 2. Case (1) demonstrates that ESG investment significantly reduced air pollution after controlling for other factors. One unit increase in ESG investment would reduce 0.334 unit of air pollution and thus increase social happiness by 0.225 unit (0.334 × 0.674). We obtained similar results in case (2), (3) and (4) by substituting environmental, social and corporate governance investments for ESG investments, respectively.

In case (5), we investigate the impact of the implementation of new environmental protection law on air pollution. Clearly, the new law's implementation dramatically reduced air pollution, which is consistent with Xu et al. (2022), who find that environmental regulations can mitigate the negative effect of air pollution on social happiness. We can infer that the new environmental protection law's ability to reduce air pollution is independent to the impact of ESG investments because there is little change in the estimates of ESG investments and a big increase in the adjusted R squared. Case (6), (7), and (8) achieved similar results to case (5) when environmental, social and corporate governance investments was substituted for ESG investments.

To check the robustness of our results, we substitute the PM2.5 and PM10 for AQI as dependent variable in Equation 2. These results are reported in Tables 4, 5, respectively. Again, ESG investments dramatically reduced PM2.5 and PM10 levels. The new environmental protection law continues to have a significant impact on reducing

PM2.5 and PM10, similar to the findings from Table 3, independent of the influence of ESG investments.

Overall, our findings imply that by reducing China's air pollution issues, ESG investments and the new environmental protection law considerably increased social happiness.

5 Conclusion

With China's rapid economic development, air pollution has severely harmed social happiness and government satisfaction. The Chinese government enacted a new environmental law in 2015 in order to control air pollution and achieve sustainable economic growth. This paper contributes to the literatures by investigating the impact of ESG investment strength and China's new environmental law on social happiness. Unlike previous studies, we conduct our research from a macro perspective, focusing on social happiness rather than subjective happiness at the individual level.

According to our findings, ESG investments improved social happiness by reducing air pollution. One unit increase in ESG investments reduced air pollution by 0.334 unit while improve social happiness by 0.225 unit. These results are consistent with Shi and Yu (2020), which show the casual effect between air pollution and individual subjective wellbeing. On the other hand, the implementation of the new environmental law has a significant impact on reducing air pollution and improving social happiness. The impact of the new law is independent of ESG investments. These results are in line with Guo et al. (2020), which suggests the positive effect of environmental regulations on happiness during 2013 and 2015 in China. Our findings show that the Chinese government and industries have made significant strides in environmental protection over the last decade. China's economy is rapidly progressing toward sustainable development. However, as long as the reliance on thermal power continues, sustainable development goals can hardly be achieved. The use of clean energy and its social impact could be of great importance for future research.

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

PL conducted the empirical analysis and wrote the paper. Conceptual design is performed by PL, SH and ST

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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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Supplementary material

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How sustainable business model innovation and green technology innovation interact to affect sustainable corporate performance

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Sustainable business model innovation (SBMI) and green technology innovation (GTI) are keys to creating shared social and business value, and both are essential elements of responsible innovation. However, SBMI or GTI is unable to develop a sustainable business. The main purpose of this study is to analyze sustainable dual innovation as a conceptual framework based on the panel data of 1468 Chinese manufacturing A-share listed companies from 2010 to 2020, and it has obtained three essential findings. First, there is a significant matching effect between SBMI and GTI on sustainable corporate performance (SCP). Companies report higher levels of SCP when there is a higher congruence in SBMI with GTI. Secondly, organizations with high SBMI-low GTI realize superior SCP compared to organizations with low SBMI-high GTI. The high SBMI-low GTI becomes an ideal choice for most companies and avoids the "destructive factors" brought by low SBMI-high GTI. Finally, a highly aggressive corporate strategy has a "magnifying effect" on the impact of the combination of SBMI and GTI on SCP. The research provides a comprehensive understanding and collective impact of SBMI and GTI on SCP. Overall, findings provide a theoretical basis for enterprises to decide on the consistency/inconsistency trade-off between SBMI and GTI. Moreover, it encourages to enterprises must develop an aggressive strategy to balance.

KEYWORDS

sustainable business model innovation, green technology innovation, sustainable corporate performance, degree of strategic aggressiveness, matching effect, amplification effect

1 Introduction

Sustainable development is now widely accepted, and businesses must innovate and implement sustainable initiatives as environmental problems become serious issues (Albitar et al., 2022). While green innovation is an essential element of sustainable development (Le, 2022), enterprises relied on green technology innovation (GTI) or sustainable business model innovation (SBMI) single path, which could not meet the requirements of sustainable development in the past.

According to Kluza et al. (2021), and Liao and Li (2022), SBMI and GTI are considered as most suitable for sustainable corporate performance (SCP). Green strategy (GS) is introduced as a solution to corporate sustainability strategies. Practical activities such as GTIs and new sustainable business models reduce the potential of the negative impact of their operations on the natural environment. Globally prominent companies such as Apple, Ricoh, IKEA, LEGO, and Google are starting to establish sustainable business practices and agreed to increase sustainability goals, creating new business models for customers on priority bases for sustainable development (Gaiardelli et al., 2014).

However, several studies have been conducted on sustainable development from the enterprise level, and most of the studies on corporate green development are based on the perspective of green technological progress (Yang et al., 2022). In contrast, not a single study has been found on sustainable development from the perspective of BM. However, Bocken et al. (2014) shows that SBMI effectively addresses sustainable corporate development. The SCP has become an influential agenda for the Chinese government. Especially in the development context, double reduction, and industrial transformation and upgrading. Conversely, China, the leading developing country, has the world's largest manufacturing sector. One of the main pillars of economic growth has been the manufacturing industry in the past decades, which also has had a severe negative impact on the environment (Li et al., 2020). The Chinese government is actively upgrading its industries and guiding companies to focus on high-quality growth and balanced development. Moreover, sustainable development has become a global issue, and China is determined to reduce CO_2 emissions by 2030 and achieve carbon neutrality by 2060 (Xi, 2022). These pressures and policies also force companies to focus on sustainable development; SBMI and GTI become necessary for enterprises to achieve sustainable development.

The SBMI and GTI are vital to creating shared social and business value (Chopra and Narayana, 2013; Spieth et al., 2019), and both are essential elements of responsible innovation (Schwab, 2017). While many companies recognize the importance of sustainability, GTI and SBMI cannot do sustainable businesses. However, literature is available on green innovation, but most of the current literature only examines the impact of SBMI or GTI on corporate sustainability. Literature on SBMI is mainly based on an "embedded" understanding of traditional business models, injecting "sustainability" only into the issues of value proposition, value creation, value capture, and value delivery (Baldassarre et al., 2017; Velter et al., 2020; Minatogawa et al., 2022). Moreover, literature on GTI tends to favor its results on the organization's environmental or financial performance (Wang et al., 2021a; Cao et al., 2021; Ma et al., 2021). The empirical literature incorporating SBMI and GTI into an overall analytical framework to fully explain the mechanisms of action on SCP is particularly scarce, and both SBMI and GTI belong to the essential elements of green innovation. Therefore, this study aims to incorporate SBMI and GTI into a theoretical framework to investigate the effects of their interaction on SCP.

However, research on the SBMI and GTI interact to affect SCP faces two critical challenges: first, relative to GTI, existing research has focused on SBMI, which can lead to more direct business benefits, such as cost savings and new revenue streams (Schaltegger et al., 2012; Bocken et al., 2014), and improve organizational resilience (Buliga et al., 2016) and reputation (Homburg et al., 2013), therefore letting more intangible competitive advantages. It has been argued that SBMI has excellent potential to address long-term sustainability challenges (Stubbs and Cocklin, 2008; Foss and Saebi, 2017). Second, literature shows a particular interest in GTI in the long run; many business model innovations seem to have failed due to the lack of GTI cooperation (Patel, 2015; Taran et al., 2015; Geissdoerfer et al., 2018), longer-term view and paying more attention to GTI can we have a "greater future" (Lu et al., 2022; Wang et al., 2022). Several researchers in recent years provided evidence that the field of business models is increasingly progressively relevant to a scientific discipline (Boons and Lüdeke-Freund, 2013; Evans et al., 2017). Although SBMI and GTI have emerged as core elements for creating green competitive advantage (Lin and Chen, 2017; Bani-Melhem et al., 2022), literature is scared of exploring the combined effects of GTI and SBMI.

From this point of view, enterprises must maintain a balance between SBMI and GTI rather than carry out an "either-or" separate dealing to achieve a sustainable future. In addition, the company does not have sufficient resources to cope with SBMI and GTI, simultaneously characterized by high risk, initiative, and innovation.

Therefore, the following two key questions are:

Qs 1: What will be the combination of SBMI and GTI, to achieve better sustainable growth for companies?

Qs 2: Does aggressive corporate strategy amplify the impact of the interaction between SBMI and GTI on SCP?

To answer the above research questions, panel data was used for 1468 Chinese manufacturing A-share listed companies from 2010 to 2020 time period. Our results confirm that SBMI and GTI are compulsory, and there is a significant relationship between SBMI and GTI on SCP. Furthermore, the study reveals that high SBMI-low GTI is more valuable, while low SBMI-high GTI may bring more "disruptive factors." In addition, the study also finds the "amplification effect" of aggressive corporate strategies in the impact of SBMI-GTI on SCP. The study contributes theoretically to how SBMI and GTI interact to influence SCP and highlights the moderating effect of different degrees of aggressive strategy. The findings of this study also have guiding implications for corporate decision-making in specific management practices. It also helps enterprises better understand at different levels of SCP generated by various combinations of SBMI and GTI at high and low levels. Further, it provides reliable theoretical support for a strategic trade-off between different levels of aggressiveness. Finally, the limited enterprise resources generate better SCP.

This paper is organized as follows: The second part is a literature review on SBMI, GTI, and SCP. The third part proposes the hypotheses related to SBMI, GTI, and SCP, the purpose of the moderating role of corporate strategic aggressiveness in the influence of SBMI and GTI on SCP, and explains the study's conceptual model. The fourth part is about data sources and their details, as well as the reasons for using the relevant variables. The fifth section presents the results of the regression analysis, moderating effect test, and robustness test, which confirm the proposed three hypotheses in this study. The sixth section summarizes the study results, makes policy recommendations, and specifies the direction of the subsequent research.

2 Literature review

2.1 Sustainable business model innovation

In recent years, business model innovation (BMI) has been famous in academia and business practice. Many studies believe that a change in BMI can bring sustainable development in enterprises (Evans et al., 2017). Schaltegger et al. (2012), Jolink and Niesten (2015) argue that BMI can integrate sustainability into enterprise development. Since the growth of SCP brought by BMI is evident, BMI for sustainability and SBMI are technically considered as part of BMI, which is also based on BMI (Geissdoerfer et al., 2018). The success rate of business model (BM) and BMI is low. However, there are no specific data on the failure ratio of BM and BMI (Hart and Milstein, 2003; Lüdeke-Freund, 2010). Due to the increasing international pressure for sustainable development, the available BM and BMI options are limited and cannot fully control the demographic issues caused by increasing resources and environmental impacts on global development (Bocken et al., 2014). The concept of non-sustainable BM also seems outdated (Geissdoerfer et al., 2018), and the exploration from the perspective of BM and BMI cannot acclimate the objective environmental changes. It is necessary to investigate the implication and extension of related concepts and explore that from a new perspective. Which also provides impartial conditions for separating SBMI from BMI. However, Geissdoerfer et al. (2018) defines the concepts of BM, SBM, BMI, and SBMI. Compared to BM, SBM is a broader concept, encompassing all from economic values to social and environmental values (Bocken and Geradts, 2020; Shakeel et al., 2020). The SBMI is clearly defined as: Innovations that create significant positive and/or significantly reduced negative impacts for the environment and/or society, through changes in the way the organization and its value-network create, deliver value and capture value (i.e. create economic value) or change their value propositions (Bocken et al., 2014). It is also widely recognized that SBMI has enormous potential to address long-term sustainability challenges (Stubbs and Cocklin, 2008; Saebi et al., 2017). As a result, SBMI has become an essential part of more companies to remain consistently economical (Zahra et al., 2006; Baden-Fuller and Morgan, 2010; Zott et al., 2011; Robins, 2013; Wirtz et al., 2016) and create more social and economic and environmental value for more stakeholders (Geissdoerfer et al., 2018).

2.2 Green technology innovation

Although traditional technological innovation activities have produced intense material progress, and also caused significant environmental damage. There is an increasing interest in green innovation among researchers and businesses, especially with the emergence of new technologies and materials. However, GTI was not a hot issue for researchers until 2007, mainly due to the acrimony at the United Nations Climate Change Conference conducted that year and the U.S. government's eventual dramatic signing of the Bali Road Map. Since 2008, developed and developing countries have focused on emissions neutrality, and green, low-carbon technology innovation is becoming a common issue for global warming and climate change.

However, Shi and Lai (2013) show a strong contrast in the growth rate of overall publications about the GTI field between developed and developing countries, with developed countries paying more attention to GTI. Second, GTI is a global phenomenon, and research on GTI in emerging economies has increased dramatically in recent years. One possible reason is related to the Chinese government's announcement of its increased international responsibility for low-carbon economic development and its commitment to the United Nations for its emission reduction targets at the 15th International Climate Change Conference, held in Copenhagen in 2009. Currently, China has made evident progress in GTI and is at the forefront of green technology growth in specific technology areas, particularly in solar photovoltaic energy, electric vehicles, and other technologies, which are impressive and significant achievements. Compared to other countries and regions, China ranked among the world's leading countries in green technological innovation related to the environment.

However, some scholars have obtained the remarkable result of a downward trend in the growth rate of green total factor productivity in China (Zhang and Tan, 2016; Chen et al., 2018; Xu et al., 2019). Therefore, China still relies more on labor, productive capital, and natural capital for green development to promote sustainable growth by increasing green productivity. There is still a long way to go to transform the growth rate and replace old with new ones.

2.3 Sustainable corporate performance

The core of sustainable development is to promote economic growth and social development with the goal of efficiency, harmony, and sustainability, which is an important trend in the modern world (He et al., 2021). Embedding sustainability in corporate performance is one of the most important ways to achieve high-quality economic development. Most recent research on sustainable development performance focuses on the macro-level and meso-level, such as the country (Feng et al., 2017; Gao, 2019a; Du and Ma 2019), province (Liu et al., 2021; Xie et al., 2022), economic belt (Gao, 2019b; Cui et al., 2021; Chen et al., 2022), industry (Sun et al., 2021; Xu et al., 2022b; Yuan et al., 2022) and city (Jin et al., 2019; Guo and Zhou, 2021). However, few studies directly explore SCP from a micro perspective. The micro-level enterprise is the direct recipient and responder of the concept of sustainable development. Therefore, the realization path of SCP is an important area of research.

The definition of SCP has not yet been standardized and clarified. Scholars do not disagree with SCP's financial performance component but mainly disagree with non-financial performance. The triple bottom line (TBL) model of sustainable performance considers environmental and social performance components of non-financial performance. Economic sustainability relates to the organization's ability to meet its needs and expectations in a financially sound manner, social sustainability includes developing and realizing household demands and needs, including maintaining long-lasting social relationships, and environmental sustainability alludes to preserving and renewing the ecosystem for current and future generations (Jum'a et al., 2022; Larbi-Siaw et al., 2022; Ossewaarde and Ossewaarde-Lowtoo, 2020). Spangenberg et al. (2002) expanded TBL to four dimensions: social, economic, environmental, and institutional. The institutional level is complementary to the TBL ideology and is composed of organizations and rules (Gupta and Gupta, 2020). Government compliance requirements, increasingly stringent penalties, rising stakeholder awareness (e.g., customers, sustainability suppliers), and the brand benefits of being a "green company" are further driving more and more companies to focus on the green technology of their business performance (Seuring and Müller, 2008; Gupta and Gupta, 2020). Another similar and more familiar concept is corporate social responsibility (CSR). CSR emphasizes the fulfillment of social responsibility as a critical prerequisite for generating economic benefits at the corporate level (Farah et al., 2021), the contribution of CSR activities to the environment, consumers, society, and the balance of economic, environmental, and social requirements (Nikolaou et al., 2013). Most scholars who insist on "sustainable development" believe that companies should focus on CSR while pursuing economic benefits (Kolk, 2016; Xia et al., 2018; Meseguer-Sánchez et al., 2021) and that fulfilling CSR is beneficial to the long-term sustainable development of companies. Therefore, considering CSR as the primary connotation of SCP can avoid the conceptual complexity issues associated with previous studies' multidimensional understanding of SCP.

3 Research hypothesis

The SBMI and GTI are both essential elements of innovation (Baldassarre et al., 2017; Guo Y. Y et al., 2018). However, scholars only examined the impact of SBMI or GTI on SCP (Peralta et al., 2019; Jabbour et al., 2020; Wang and Yang, 2021). For example, Shakeel et al. (2020) argue that corporate SBMI improves organizational output through sustainable value proposition innovation, sustainable value creation, and delivery innovation, and sustainable value capture innovation to achieve sustainable performance at environmental, social, and economic levels. Lv et al. (2021) and Ma et al. (2021) argue that GTI cannot solve the environmental problems in the production and consumption process but also improve enterprises' market competitiveness by increasing production's sustainability. Literature is unable found incorporating both into a holistic framework. Examine the effect of one variable on SCP while controlling the other variable; otherwise, the antecedent mechanism of SCP cannot be revealed comprehensively and objectively.

The two variables have a complementary relationship; the marginal effect of one type of innovation activity will necessarily vary with the other (Milgrom and Roberts, 1995). Because both SBMI and GTI have essential effects on SCP, can the two not work together on SCP?

Task-technology matching theory provides some theoretical support for us to address this issue. According to the task-technology matching theory, new technology can only produce higher performance if it matches the task scenario, and the degree of task-technology matching directly impacts performance (Goodhue and Thompson, 1995; Li et al., 2016). The matching problem has received extensive attention from scholars in economics and sociology. The core of the matching theory is the resolution of the indistinguishability dilemma in resource allocation. Believe that SBMI and GTI are naturally complementary with significant indivisibility and that businesses can convert and match between them based on their needs.

However, the SBMI that supports it impacts the GTI's speed and characteristics. The SBMI is a non-technical innovation whose primary goal is to realize its green value. When SBMI can match GTI, SBMI will significantly affect GTI, which will help enterprises find the right direction of green technology development, improve the efficiency of green R&D activities, contribute to the transformation of GTI commercial results and support the promotion of SCP. Moreover, SBMI heavily depends on whether and how GTI is accepted in the economy. When GTI is combined with SBMI, it can help enterprises acquire core capabilities to ensure sustainable development, improve long-term adaptability to the external environment (Sahoo et al., 2022), and thus promote the improvement of SCP. Therefore, SBMI and GTI are complementary and inseparable, and their alignment promotes higher SCP.

However, mismatch between SBMI and GTI are common in the long-term development of businesses. When GTI is strong, GTI may lose SBMI's guidance in the right direction of GTI, and enterprises face the risk of a "failure trap" caused by high input costs and high-income uncertainty. However, when SBMI is strong, it will extend its extinction time due to its high stickiness with existing technology, thus impeding the next stage of GTI. It may also cause organizations to develop organizational inertia and path dependence, fall into the "success trap," and eventually struggle to adapt to drastic changes in the external environment. Despite SBMI's ability to improve SCP in the short term, enterprises face increasingly fierce market competition due to economic globalization. Short-term business performance is no longer the main focus of enterprises, and improving long-term competitiveness has moved to the top of the enterprise development priority list. When SBMI and GTI do not match, the enterprise will have a specific resource idle, which will be detrimental to SCP improvement.

Therefore, this paper proposes hypothesis 1.

H1: The SCP level is higher when SBMI is consistent with GTI when SBMI is inconsistent with GTI.

From the perspective of a resources-based view, the enterprise's resources are limited, and allocation between SBMI and GTI is in a trade-off relationship. Different input combinations will have different impacts on SCP. Therefore, the business development of enterprises is seriously affected by the accumulation of resources in the early stage. Some enterprises are more sensitive to SBMI, while others have more substantial GTI capability, which is more likely to produce path-dependent solid constraints. However, when an enterprise tries to acquire new resources, it must decide which scarce and valuable resources to acquire and how to replenish them.? Therefore, it is challenging for enterprises to balance SBMI and GTI. The SBMI and GTI are hardly consistent all the time. In particular, there are fundamental differences between SBMI and GTI (Table 1).

Based on that premise, companies tend to choose one innovation approach (e.g., SBMI) as the dominant one under certain spatial and temporal conditions and then switch to another innovation approach (e.g., GTI) under other spatial and temporal conditions to realize the founder of SBMI and GTI on a larger geographical and temporal scale. When SBMI and GTI are inconsistent, it is more practical to discuss the mechanism of the effect on SCP.

There are two cases when SBMI and GTI are inconsistent: high SBMI-low GTI and low SBMI-high GTI.

In the first case, the SBMI level is higher than the GTI level. Although SBMI has drawbacks, the most obvious is low entry barriers. Due to resource constraints and the business philosophy of "living in the present," many companies must choose between SBMI and GTI and choose high SBMI-low GTI. According to a survey conducted by the Economist Intelligence Unit in 2005, more than half of executives believe BMI is more important than product and service innovation. Companies are paying more attention to SBMI, which helps unlock the potential value embedded in technology, capturing as much value as possible and converting technology into market revenue. This is particularly important for businesses in their early stages.

The colossal risk of GTI itself, which cannot guarantee the commercial success of enterprises, is an important reason why these enterprises are willing to choose high SBMI-low GTI. According to Schumpeter's theory of innovation, "innovation is the commercial application of an invention patent," and R&D that cannot be commercialized to bring sufficient company profits is not considered successful technological innovation. An intriguing phenomenon is that many companies, including investors, cannot assess GTI's prospects. Warren Buffett has been asked what he looks for the most when investing in businesses (Rajaratnam et al., 2011). "Business Model" has become a buzzword among operators and venture capitalists.

The SBMI level is lower than the GTI level in the second case. Companies that choose low SBMI-high GTI are willing to give up short-term benefits to pursue long-term goals because they believe that being technically rigid is the only way to achieve actual, sustainable development. Companies that adopt a low SBMI-high GTI business model do not choose the high GTI business model but go through a continuous adjustment process. China's photovoltaic industry is a prime example. This capital- and technology-intensive emerging industry has enormous growth potential but is also rife with destructive innovations. Looking at the tragic wave of China's photovoltaic industry, only those corporations that prioritize investment in green technology R&D have survived to the present day, while those that overly pursue the capital logic of BMI have almost all fallen and gone up in smoke.

However, pursuing GTI entails greater risk (Cooper, 1981; Roper and Tapinos, 2016; Xue et al., 2022). Compared to high SBMI-low GTI, low SBMI-high GTI does not ensure good long-term enterprise performance. These are the following factors:

First, consider the characteristics of green technology. Long development cycles, high costs, high risks, and low profits distinguish green technologies. The enormous risks of green technology development will make companies cautious in the absence of economic scale effects to amortize the expensive technology investments and operating costs. Evidence suggests that industries in desperate need of green technologies, such as steel, petrochemicals, and other heavy pollution manufacturing industries, have average profit margins at the bottom of the "smile curve" and cannot afford the high GTI costs, limiting green technology adoption and development by enterprises in these industries. (Hu et al., 2021; Yin et al., 2021; Chen and Zheng, 2022).

Second, insufficient R&D motivation for green technology. As opposed to general technology, green technology is primarily reflected in social and ecological benefits, which do not directly benefit enterprises but increase their economic costs. Government environmental regulations primarily drive the current market demand for so-called green technology. Government subsidies provide many funds for corporate GTI in developing countries, but government subsidies distort factor markets. The picture of insufficient power sources for GTI will emerge once the government implements a subsidy retreat policy.

Third, the company's security awareness. There is no universal formula. Different definitions of success frequently influence a company's strategic positioning. A common understanding is that risk avoidance is a general prerequisite for business continuity; for example, "financial stability" may be considered a "safety factor." (Subramaniam et al., 2011; Florio and Leoni, 2017). High SBMI-low GTI is considered more valuable to increase enterprises' sustainable development, whereas low SBMI-high GTI may bring more "disruptive factors." Each business success is unique, but based on common sense and extensive empirical findings, high SBMI-low GTI is the preferred choice for most businesses.

Therefore, proposed hypothesis 2:

H2: When the result of SBMI is inconsistent with GTI, firms with the high SBMI-low GTI have higher levels of SCP than those with the low SBMI-high GTI.

Only a few studies on the degree of strategic aggressiveness have been conducted. However, the "strategies are positioned along a continuum" concept proposed by Dent (1990) provides an excellent analytical framework for determining strategic aggressiveness. The current typology of strategic aggressiveness in the literature is based on Miles and Snow's corporate strategy taxonomy proposed in 1978 and 2003, respectively (Mintzberg and Waters, 1985; Fiss, 2011; Kong et al., 2020), which classifies corporate strategies as prospectors, defenders, and analyzers. These strategies are continuous, with defenders, prospectors at the extremes, and analysts in the middle with both defender and prospector characteristics. Here is proposed the following model of the degree of strategic aggressive continuum's great extent (Figure 1), drawing on Miles and Snow (1978, 2003) strategy classification.

The strategic aggressiveness amplifies the impact of the SBMI and GTI on SCP, specifically through the three aspects described below.

First, companies with a high degree of strategic aggressiveness have a strong incentive to mobilize more resources in the process of promoting SBMI and GTI, and they concentrate on rapidly advancing new green technologies, green product development, and creating new SBM, with an emphasis on "open source" rather than "cost-cutting" (Kabanoff and Brown, 2008). Therefore firms with a high degree of strategic aggressiveness have a greater need for long-term investment in green product development and green market expansion, even if it means taking the risk of "short loan and long investment." (Ye et al., 2021) and using more social networks to seek support from local governments (Song et al., 2016; Xu et al., 2022a). Furthermore, companies with a high degree of strategic aggressiveness tend to attract a large and diverse marketing and R&D team, are results-oriented, and measure their performance through customer-centric metrics (Olson et al., 2005; Zhang and Li, 2009).

Second, companies with a high degree of strategic aggressiveness have higher confidence or risk appetite when advancing SBMI and GTI. Companies with a high degree of strategic aggressiveness typically have a broad focus and are constantly developing. Firms with a high degree of strategic aggressiveness are prone to "overconfidence." The CEO's overconfidence is not solely due to cognitive bias. According to Yun et al. (2021), overconfident CEOs prefer different competitive strategy options, resulting in significant differences in the degree of aggressiveness of corporate behavior. Papadakis and Barwise (2002) believe that CEO characteristics are related to the degree of strategic aggressiveness. Firms with a high degree of strategic aggressiveness choose significantly advanced exploratory green innovation and constantly invent green technology products and green services to capture and exploit new opportunities in new green product markets. The CEO's confidence is critical for hazardous exploratory green innovation activities. According to research on organizational behavior, aggressiveness and overconfidence are associated with the CEOs of many great companies (Hirshleifer et al., 2012; Gilbey et al., 2021; Wang et al., 2022).

Third, companies with a high degree of strategic aggressiveness develop and maintain the ability to understand and adapt to environmental changes. Companies with a high degree of strategic aggressiveness are more likely to be able to advance SBMI and GTI systematically, often in tandem with credit loss strategies in other areas of the field (Taran et al., 2015; Forés, 2019; Peng, 2020; Liu and Kong, 2021). To analyze new opportunities for green products, firms with a high degree of strategic aggressiveness must be able to investigate

TABLE 1 Differences and connections between SBMI and GTI.

Items		SBMI	GTI
Differences	**Nature**	• Constructs a new trading structure (Geissdoerfer et al., 2018)	• Creates positive meaning and value for the environment (Wang et al., 2021b)
	Core logic	• Emphasizes broadening the value chain and creating more green value space by making more trading partners (Geissdoerfer et al., 2016)	• Emphasizes sustainable development by building its core capabilities (Wicki and Hansen, 2019)
	Time preference	• Often a strategic choice for companies in their start-up stage with low investment, quick results, and low risk (Schaltegger et al., 2012)	• Often a strategic choice for the growth stage of a company with significant investment, slow payoff, and high risk (Feng et al., 2022)
	Externality	• Pays more attention to intellectual property protection of BMs with the characteristics of low threshold, easy replication, and rapid scale (Lindgardt et al., 2012)	• The existing intellectual property protection system ensures recourse to infringement with long investment cycles and high barriers to competition (Losacker, 2022)
Connections	**Dual wheel drive**	• If a good SBM can be designed for stakeholders as a way to drive GTI and sell innovative products, it will be a win-win situation for both parties (Guo et al., 2022)	• The drive of BM can lead the development direction of GTI, so there must be SBMI that can realize the value of green technology to the maximum (Wicki and Hansen, 2019)
	Single wheel drive	• In the absence of GTI or related resources, the high growth generated by SBMI may be short-lived due to simple competition for capital and the lack of adequate thresholds (Stubbs and Cocklin, 2008; Yang et al., 2017)	• If not matched with SBMI, GTI is only a pure cost center, which cannot create market value and cannot be translated into corporate profits, and may end up in failure (Xia et al., 2019; Goni et al. (2021)

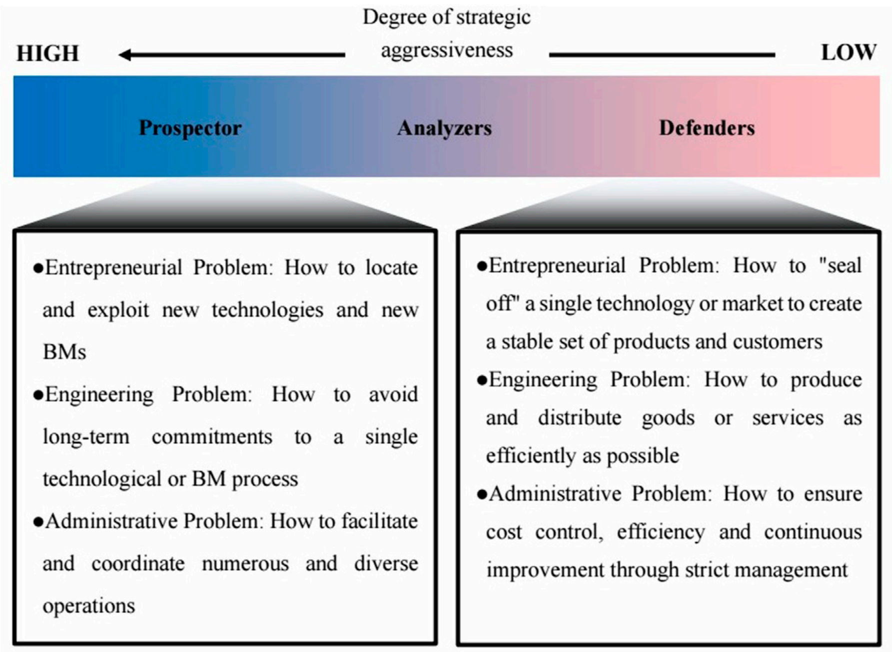

FIGURE 1
A continuum model of the degree of strategic aggressiveness.

environmental conditions. Trends thoroughly and events, analyze the environment for potential opportunities of all kinds, and these scanning activities must not be limited to current technology and business areas (Walker and Brewer, 2009; Gumusluoglu and Acur, 2016; Nath and Siepong, 2022). Firms with a high degree of strategic aggressiveness are more likely to perceive environmental change and uncertainty than firms with a low degree of strategic aggressiveness.

Therefore, proposed hypothesis 3.

H3: The high degree of corporate strategic aggressiveness amplifies the effect of SBMI and GTI on SCP.

The following conceptual model is proposed in this study (Figure 2).

4 Materials and methods

4.1 Data and sample

This study's sample consists of manufacturing firms listed in China A-shares from 2010 to 2020. Compared to other types of

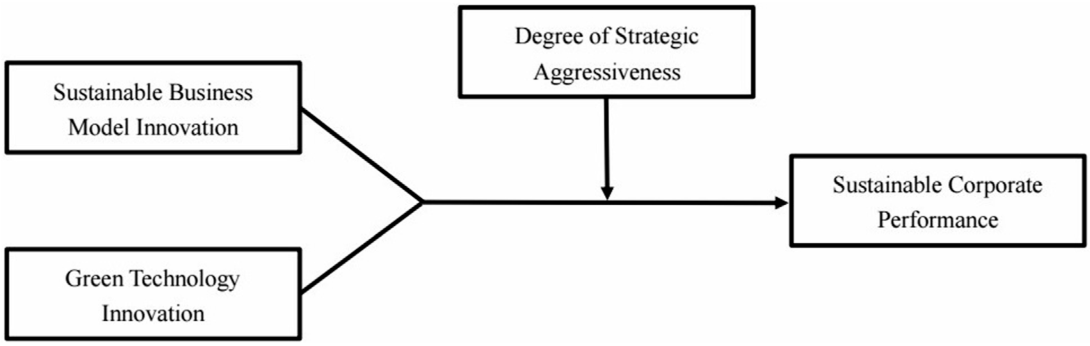

FIGURE 2
Conceptual model of this study.

enterprises, such enterprises are complete in many aspects, including procurement, R&D, production, and sales (Xiao and Zhang, 2021), and rich SBMI sample data can be collected. Furthermore, manufacturing firms are more willing to transform their R&D and green technological accomplishments, and their GTI characteristics are visible. Listed Chinese manufacturing enterprises are selected for the survey.

Four main data sources are used, China Stock Market and Accounting Research (CSMAR), Chinese Research Data Services Platform (CNRDS), Hexun CRS database, and the Cninfo website are the primary data sources. The CSMAR is one of China's largest databases of listed companies and a major source of information on the Chinese stock market and listed companies' financial statements. CNRDS is a high-quality, open, platform-based aggregate data platform for economic, financial, and business research in China, covering listed companies' innovation patents, green patents, and text information. In China, Hexun CRS database was an early third-party provider of social responsibility performance scores based on annual and social responsibility reports from listed companies total CSR score of a company is split into five dimensions: (1) shareholder, (2) employee; (3) supplier, customer, and consumer; (4) environmental; and (5) social responsibility. The China Securities Regulatory Commission's Cninfo website publishes financial reports, announcements, and other information from listed companies. To ensure the accuracy of the data, we cross-check it against the annual reports of listed companies provided by the Cninfo website and company websites. The initial sample is as follows: (1) We exclude listed companies that have a severe lack of variables; (2) Exclude listed companies that have financial irregularities, such as special treatment (ST and ST*).; (3) Exclude from the analysis any listed enterprises that left the Stock Exchange during the investigation period. Examine the distribution of variable values and notice some rather extreme outliers. Many studies have discarded outliers, but doing so would have resulted in the loss of some of the data (Henderson et al., 2012). To avoid outliers adversely affecting the results, we adopt 99% winsorization, drawing on Flammer and Bansal (2017) and Shiu and Yang (2017). Finally, after merging the data and eliminating firms with missing values, this paper obtains 7090 unbalanced panel data for 1468 listed firms over the sample period.

4.2 Dependent variable

4.2.1 Sustainable corporate performance (SCP)

According to previous studies, SCP consists of financial performance and CSR. The financial performance measure is based on returns on assets (ROA), and the social responsibility score of HeXun measures CSR. We use the more objective catastrophe progression to overcome the subjectivity of the design weights when determining financial performance and CSR weights (Zuo et al., 2021). Further measure SCP using ROA and the total CSR score from 2010 to 2020. This paper uses SCP lagged one period for the robustness test.

4.3 Explanatory variables

4.3.1 Sustainable business model innovation (SBMI)

The existing methods of measuring SBMI are mainly the interview (Geissdoerfer et al., 2016; Todeschini et al., 2017; Yip and Bocken, 2018) and the questionnaire (Cheah and Ho, 2019; Peralta et al., 2019). The former method is mainly targeted at senior managers familiar with corporate sustainable business models, but to a certain extent, it is affected by respondents' characteristics and understanding of limitations. The latter has high labor costs and the dilemma of poor replicability and low generalizability.

With the rapid development of machine learning, many scholars have started to use textual analysis techniques to extract the value information from listed companies' disclosures (Wang K. M et al., 2018). Currently, there are two main types of textual analysis: the first method is lexicon which counts word occurrences from word lists (dictionaries), and the second is a combination of keyword search and manual counting. However, several challenges arise when applying these approaches to measuring SBMI. Word lists (dictionaries) that share common meanings do not consider the textual language environment. Although the combination of keyword search and manual scoring overcomes the drawbacks of the first method, it still has a high human cost and relies on the empirical judgment of researchers to a high degree. The word frequency analysis method of seed words + Word2Vec similar words expansion + specific dictionary is a good choice. This method overcomes the shortcomings of the previous two methods by selecting a small number of representative words, potentially saving labor costs. The Word2Vec model is trained

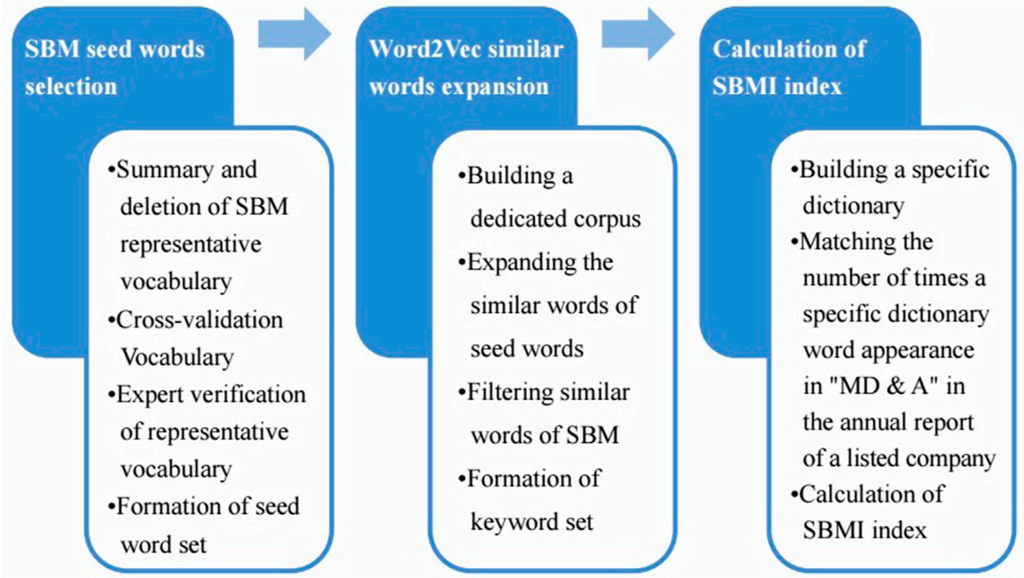

FIGURE 3
Diagram of proxy variable construction for SBMI.

using a specialized corpus of "MD and A" seed words to find similar words that match the target language environment and form a specific dictionary. Therefore SBMI has calculated the ratio of the total number of times a word from the SBM-specific dictionary appears in the "MD and A" section of a company's annual report for the year to the total number of words in the text. The more SBM words mentioned in the "MD and A" section, the more effort enterprises put into SBMI, and the ratio measurement method can highlight the importance of these words. The specific construction steps are shown in Figure 3.

Step 1: SBM seed word selection. Based on the definition and characteristics of SBM described by Joyce and Paquin (2016), SBM representative words are summarized and screened at first. Delete the words that do not fit the SBM connotation and identify the semantically ambiguous words. Drawing on Denzin, 2017, words are cross-validated through materials and literature from multiple sources. These words must be screened and supplemented. The revised SBM word set is also verified by three SBM field experts, resulting in a seed set of SBM words.

Step 2: Word2Vec similar words expansion. Expansion of similar words in Word2Vec. Expressions use multiple semantically similar words to describe the same concept or thing; after selecting the seed set of words, it is necessary to expand the similar words. Therefore, following Li et al. (2021), this paper uses the Word2Vec model to realize the expansion of similar words based on the particular corpus of "MD and A" in the annual reports of listed companies. After eliminating repeated words and some low-frequency words, the remaining similar words were analyzed by three professional researchers. The words that are all approved are added to the keyword set.

Step 3: Calculation of SBMI index. Following the acquisition of the SBM keyword set, experts are invited to conduct verification, and the keyword set is confirmed again comparing text samples from annual reports of listed companies to form the SBM-specific dictionary. SBMI is represented by a ratio of the number of times words from the SBM-specific dictionary appear in the annual report "MD and A" to the total number of words in the text. Lv et al. (2018), to keep the SBMI comparable with the GTI, scale normalization is applied to it so that it falls into the 0 to 1 range.

4.3.2 Green technology innovation (GTI)

There are two main types of existing methods to measure GTI. One is the factor input method, including enterprise R&D expenditure (Fan and Chu, 2019), the sum of internal expenditure on R&D and investment in technological transformation (Bi et al., 2011; Wang F. Z et al., 2018), *etc.* Second is the factor output method, including the number of green patents (Klemetsen et al., 2018; Qi et al., 2018; Barbieri et al., 2020), new product sales revenue per unit of energy consumption (Guo Y et al., 2018). R&D expenditure does not effectively distinguish between GTI and non-GTI; new product sales revenue is not unavailable to all enterprises with relevant data. As a result, the above measurement methods are not used in this paper, and the absolute number of green patents and the relative proportion of green patents are the two main ways to measure GTI by patents. Although the number of green patents can reflect the level of corporate GTI, the proportion of green patents to all patents more accurately reflects corporate GTI direction (Wang and Zhao, 2019). There will be withdrawal and rejection in the process of patent application (Lei and Wright, 2017); this study refers to Cai et al. (2019) and Chang et al. (2015) to select a more reliable number of authorized patents. The basic measurement method of GTI is as follows:

$$\frac{\ln\ (Number\, of\ green\ patents\ granted + 1)}{\ln\ (Number\, of\ patents\ granted + 1)}$$

Because of the more stringent application and granting conditions, the quality of invention patents is also higher (He et al., 2018; Mao et al., 2018). The number of green invention patents granted and the number granted for robustness testing are used in this study. Following Lv et al. (2018), scale normalization is applied to the GTI so that it falls into the 0 to 1 range to keep it comparable with the SBMI.

4.3.3 Degree of strategic aggressiveness (STRATEGY)

Bentley et al. (2013), developed a discrete composite measure that proxies for strategic aggressiveness. Companies with higher scores have a high level of strategic aggressiveness, while companies with lower scores have a low level of strategic aggressiveness. For the composite measure of strategic aggressiveness, we use the following characteristics: (1) the R&D to sales ratio, (2) the employee to sales ratio, (3) a historical growth measure (1-year percentage change in total sales), (4) the marketing and administrative expenses to sales ratio, (5) a measure of employee fluctuations, and (6) the fixed assets to total assets ratio. Following Ittner et al. (1997), all variables are calculated using a 5-year rolling average. The first five individual variables are ranked within each year's industry by forming quintiles. For each variable, observations in the highest quintile are assigned a score of 4, the second-highest quintile is assigned score of 3, and so on, while those in the lowest quintile are assigned a score of 0. Those observations are assigned a score for the sixth variable is the inverse of the preceding principle. Observations in the highest quintile with the sixth variable receive a score of 0, while those in the lowest quintile receive a score of 4. Each company year, add the scores from the six variables, with a maximum score of 24 (high degree of strategic aggressiveness) and a minimum score of 0 (low degree of strategic aggressiveness).

4.4 Control variables

Senior manager equity incentives (*ln_mh*). Some enterprises' senior managers do not hold shares; the natural logarithm is calculated after adding 1 to the original data. Equity incentives, which are highly correlated with the firm's business conditions, are one of the most important sources of income for senior managers (Elsilä et al., 2013; Kim et al., 2016). Therefore, corporate executives' pay is closely related to SCP. As a result, we control the number of shares held by senior management.

Senior manager compensation incentives (*ln_mss*). The total salaries of senior executives are calculated using the natural logarithm. Salary is another source of income for senior managers, and it is also highly correlated with business performance (Chen and Jermias, 2014), which further leads to the high correlation between the income of senior corporate managers and SCP. Therefore, control for total senior manager salaries.

Industry competitiveness (*HHI*). The Herfindahl-Hirschman Index measures each listed company's market share (based on SIC three-digit industry codes) (Wang and Zhang, 2015). It has been observed that industry competition and financial performance are not linearly related, with neither low nor high levels of industry competition having a positive impact on financial performance and medium levels of industry competition. They effectively reduced firm costs and improved firm financial performance (Schmidt, 1997). Industry competitiveness affects SCP in a curve-related manner. Also include an industry competitiveness control in the regression analysis.

Key pollution monitoring unit (*KPMU*). The value is 1 if it belongs to a key pollution monitoring unit; otherwise, the value is 0. Some studies consider whether a company is a key pollution monitoring unit in its environmental management system. This system certification promotes environmental compliance and improves the environmental performance in the enterprise (Yu and Bi, 2021), while also influencing SCP. Therefore the variable of whether a key pollution monitoring unit is controlled.

The number of listing days (*ln_ld*). The natural logarithm is used for measurement. The longer it has been since the first listing, the more openly disclosed corporate information (Chen and Mu, 2018) and controlled the number of days.

Financial subsidies (*ln_fn*). Because the number of financial subsidies received by the enterprise maybe 0, the natural logarithm is computed after adding 1 to the original data. It is widely accepted that government subsidies positively impact firm performance (Zheng et al., 2021).

The concentration of equity (*LHR*). The largest shareholder's shareholding rate is used for measurement. Previous perspectives on the effect of equity concentration on performance have been inconsistent with Jensen and Meckling (1976), arguing that an increase in corporate equity concentration enhances the firm's value. In contrast; Farooq (2015) argues that an increase in equity concentration causes information asymmetry problems, which affects the firm's debt ratio and worsens its financial position, jeopardizing the steady development of corporate performance. Furthermore, equity structure non-linearly impacts firm performance (Du and Liu, 2002; Zhang et al., 2019). The equity concentration is under control by rigorously considering scientific research.

Nature of equity (*EN*). If it is a state-owned enterprise (SOE), code it as 1; otherwise, code it as 0. In China, SOEs generally bear a policy burden and prioritize social performance over economic performance, and SOEs do not outperform non-SOEs in terms of economic performance (Li and Li, 2019). Therefore the nature of equity that may affect SCP is under control.

4.5 Statistical analysis

It should be noted that the measurement methods of consistency and inconsistency of the two "inseparable" variables in this study are primarily difference scores and interaction terms. These scores have consisted of the algebraic, absolute, or squared difference between two component measures (e.g., Alexander and Randolph, 1985; Dougherty and Pritchard, 1985; Turban and Jones, 1988; Rice et al., 1989; Tubbs and Dahl, 1991). However, combining two measures into a single index with different scores may result in information loss, making the index unreliable (Edwards, 1993; Edwards and Parry, 1993). In addition, a product term does not represent the effects of consistency (Edwards, 2001). That is, we have no way to know whether each component of the final index contributes uniquely to predicting outcomes or if only one component does so (Lubatkin et al., 2006). However, polynomial regression equations contain the component measures composing the difference and specific higher-order terms, such as the squares of both component measures and their product (Edwards, 1994). Therefore, polynomial regression is not only used to represent consistency (i.e., fit, match, similarity, or agreement) between two variables, but it also allows to avoid many of the problems associated with different scores and interaction terms (Edwards, J. R., and Parry, 1993). Furthermore, The three-dimensional

TABLE 2 Descriptive statistics and correlations of the main variables.

Variables	1	2	3	4	5	6	7	8	9	10	11	12
1.SCP	1											
2.SBMI	0.124***	1										
3.GTI	−0.001	0.045***	1									
4.STRATEGY	−0.034***	0.023*	−0.008	1								
5.ln_mh	0.034***	0	0.051***	0.198***	1							
6.ln_mss	0.271***	−0.076***	0.201***	−0.001	0.179***	1						
7.HHI	−0.015	−0.078***	−0.038***	−0.066***	−0.071***	−0.030**	1					
8.KPMU	−0.019	−0.134***	0.068***	−0.139***	−0.015	0.180***	0.006	1				
9.ln_ld	0.032***	−0.100***	0.063***	−0.280***	−0.398***	0.192***	0.061***	0.213***	1			
10.ln_fn	0.177***	0.039***	0.223***	−0.033***	0.032***	0.305***	0.057***	0.069***	0.136***	1		
11.LHR	0.160***	0.054***	0	−0.081***	−0.236***	0.024**	0.085***	0.043***	0.054***	0.124***	1	
12.EN	0.071***	0.058***	0.066***	−0.207***	−0.477***	0.073***	0.044***	0.074***	0.504***	0.111***	0.229***	1
Mean	0.759	0.303	0.314	11.580	10.865	14.964	0.100	0.269	8.338	16.516	32.233	0.402
Std	0.063	0.198	0.296	4.405	7.054	0.774	0.080	0.444	0.475	1.742	13.305	0.490
Min	0.190	0	0	0	0	13.102	0.022	0	7.526	10.820	9.090	0
Max	0.984	1	1	24	19.966	17.073	0.365	1	9.163	20.471	69.280	1

n = 7090. ***, **, and * indicate significance at the levels of 1%, 5%, and 10%, respectively.

response surface analysis based on a polynomial regression presented the effect of two variables and their consistency and inconsistency on the dependent variable, which helps to explain the consistency and inconsistency effect more effectively (Ilmarinen et al., 2016). The polynomial regression and response surface analysis to investigate how SBMI and GTI interact to affect sustainable corporate performance.

4.5.1 Polynomial regression estimation

Polynomial regression estimation is the construction of interaction terms ($X_1 \times X_2$) and quadratic terms (X_1^2; X_2^2) based on two consistent (inconsistent) predictor variables (X_1; X_2), thus including X_1, X_2, X_1^2, $X_1 \times X_2$, and X_2^2 simultaneously in the regression analysis of the dependent variable (Shanock et al., 2014). Accordingly, this paper constructs polynomial regression models:

$$SCP = b_0 + b_1 SBMI + b_2 GTI + b_3 SBMI^2 + b_4 SBMI \times GTI + b_5 GTI^2 + b_6 C + \varepsilon \tag{1}$$

where SCP represents sustainable corporate performance, $SBMI$ represents sustainable business model innovation, GTI represents green technology innovation, C represents control variables, b_0 is intercept, b_1 and b_2 are the coefficients of the first term, b_3 and b_5 are the coefficients of the second term, b_4 is the coefficient of the interaction term, and ε represents the random error term.

The study used polynomial regression and response surface analysis to test for consistency and asymmetric inconsistency effects in Hypothesis 1 and 2 (Edwards and Parry, 1993; Herhausen, 2016). Three-dimensional response surfaces generated from polynomial regressions are used to examine the impact of consistent (inconsistent) predictor variables on the outcome variables (Edwards and Parry, 1993; Edwards and Van Harrison, 1993). In response to surface analysis, the slope and curvature of the inconsistency line ($SBMI = -GTI$) are tested. According to Edwards and Parry (1993), if Hypothesis 1 is supported, ($b_3 - b_4 + b_5$) should be negative and significant. If Hypothesis 2 is supported, ($b_1 - b_2$) should be positive and significant.

4.5.2 Moderation test

Finally, a hierarchical regression analysis is applied to test the moderating effects of the degree of strategic aggressiveness on the relationship between SBMI-GTI inconsistency and SCP (see Hypothesis 3). Different from linear regressions in which the statistical significance of the coefficient for a three-way interaction should be assessed to establish a three-way moderating effect, in polynomial regressions, the increment in R^2 after adding a moderator and products of the moderator with each of the original terms should be assessed to establish the moderating effect (Edwards and Rothbard, 1999). Specifically, the following equation is formulated to test Hypothesis 3:

$$\begin{aligned} SCP = {} & b_0 + b_1 SBMI + b_2 GTI + b_3 SBMI^2 + b_4 SBMI \times GTI + b_5 GTI^2 \\ & + b_6 STRATEGY + b_7 STRATEGY \times SBMI \\ & + b_8 STRATEGY \times GTI + b_9 STRATEGY \times SBMI^2 \\ & + b_{10} STRATEGY \times SBMI \times GTI + b_{11} STRATEGY \times GTI^2 \\ & + b_{12} C + \varepsilon \end{aligned} \tag{2}$$

TABLE 3 Results of polynomial benchmark regression and response surface analysis.

	Model 1		Model 2		Model 3	
Control variables						
ln_mh	−0.0002	(0.0003)	−0.0002	(0.0003)	−0.0002	(0.0003)
ln_mss	0.0139[a]	(0.0023)	0.0142[a]	(0.0023)	0.0141[a]	(0.0023)
HHI	−0.0092	(0.0252)	−0.0105	(0.0253)	−0.0094	(0.0253)
KPMU	−0.0042[b]	(0.0021)	−0.0037[c]	(0.0021)	−0.0038[c]	(0.0021)
ln_ld	−0.0743[a]	(0.0053)	−0.0695[a]	(0.0056)	−0.0695[a]	(0.0057)
ln_fn	0.0021[a]	(0.0005)	0.0021[a]	(0.0005)	0.0020[a]	(0.0005)
LHR	0.0003	(0.0002)	0.0003	(0.0002)	0.0003	(0.0002)
EN	0.0052	(0.0080)	0.0051	(0.0080)	0.0053	(0.0080)
Independent variables						
SBMI (b_1)			0.0114[b]	(0.0050)	0.0169[a]	(0.0058)
GTI (b_2)			−0.0086[b]	(0.0038)	−0.0084	(0.0062)
$SBMI^2$ (b_3)					0.0012	(0.0138)
SBMI×GTI (b_4)					0.0323[b]	(0.0136)
GTI^2 (b_5)					−0.0193[c]	(0.0115)
Response surface analysis						
Congruence line:SBMI = GTI						
Slope (b_1+b_2)					0.0085	(0.0093)
Curvature (b_3+b_4+b_5)					0.0143	(0.0217)
Incongruence line: SBMI = −GTI						
Slope (b_1-b_2)					0.0253[a]	(0.0076)
Curvature (b_3-b_4+b_5)					−0.0504[b]	(0.0238)
R^2	0.0858		0.0878		0.0894	
F	32.0125		27.3314		21.4504	

n = 7090. Robust standard errors are shown in parentheses.
[a]p < 0.01.
[b]p < 0.05.
[c]p < 0.1.

Where $STRATEGY$ represents the degree of strategic aggressiveness. According to the above model, the moderation effect of $STRATEGY$ should depend on the joint effects of b_7, b_8, b_9, b_{10}, and b_{11}. If the increment in R^2 is statistically significant. Furthermore, interpretation can be conducted by examining the shape of the response surfaces at different levels of the moderator.

5 Empirical results and analysis

5.1 Descriptive statistical analysis

Table 2 represents the descriptive statistics of the main variables. The mean value of *SCP* is 0.759, and the standard deviation is 0.063, indicating a significant variation in SCP between each firm. The mean values of *SBMI* and *GTI* are 0.303 and 0.314, respectively, with both minimum values of 0 and maximum values of 1. However, the standard deviations are 0.198 and 0.296, respectively, indicating significant differences in SBMI and GTI among enterprises.

Table 2 also shows the correlations between the variables used in our study. $SBMI$ is positively correlated with SCP (r = 0.124, p < 0.01), GTI (r = 0.045, p < 0.01), and $STRATEGY$ (r = 0.023, p < 0.1). GTI is no significant correlated with SCP and $STRATEGY$. However, the effect of SBMI-GTI interaction on SCP and the moderating effect of the degree of strategic aggressiveness rather than a simple pairwise variable correlation. Therefore, the results indicate further regression analysis.

5.2 Analysis of regression results

Before the polynomial regression, in order to reduce multicollinearity and facilitate the interpretation of the results, the explanatory variables for constructing interaction terms are centered

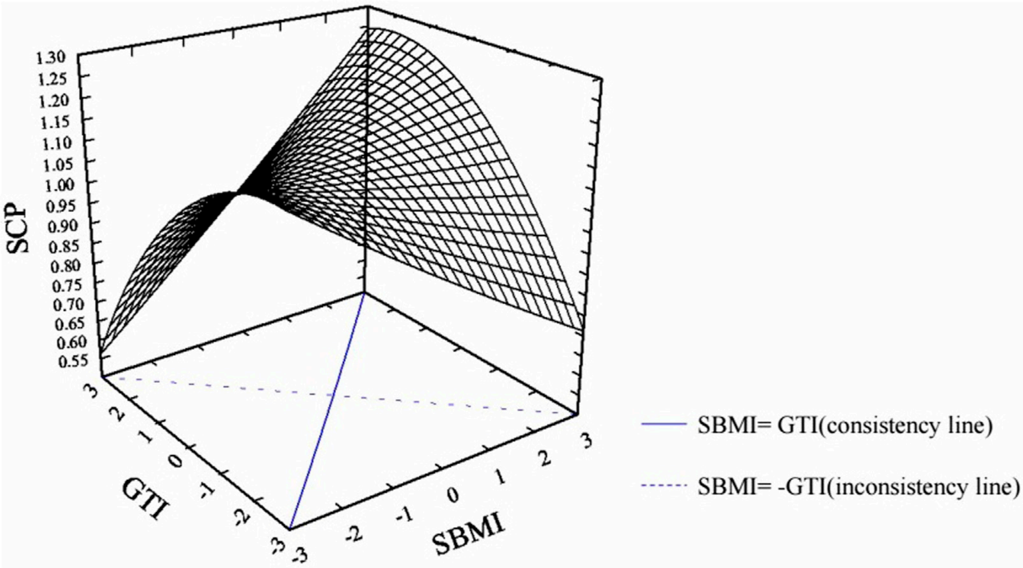

FIGURE 4
Surface graph of SBMI-GTI consistency/inconsistency on SCP.

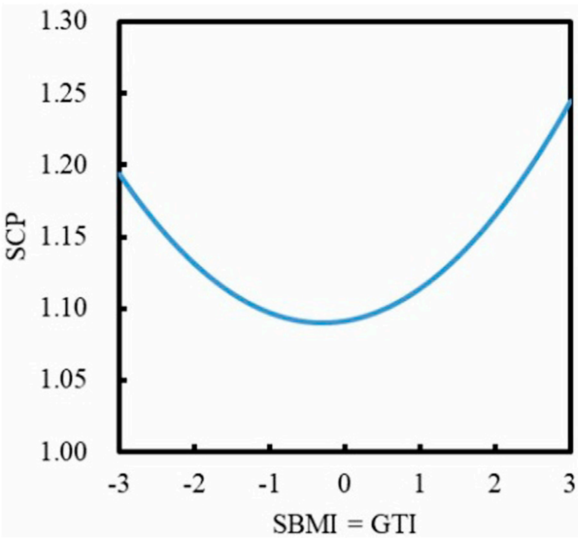

FIGURE 5
Side view of response surface along consistency line.

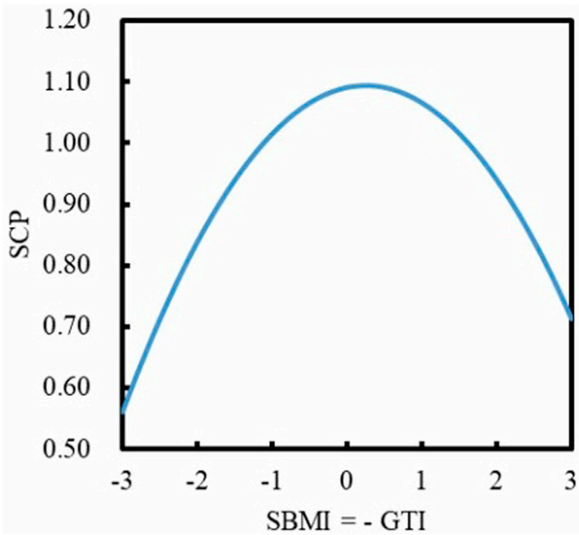

FIGURE 6
Side view of response surface along inconsistency line.

in this paper. The variance inflation factor (VIF) diagnosis is performed for all input variables of the regression models. The results show that the mean value of VIF is 2.15, falling far below 10, so there is no multicollinearity. In addition, to avoid the problems of serial correlation, autocorrelation, and heteroscedasticity that may exist in panel data regression analysis, as well as the endogeneity problems caused by omitted variables, the fixed effect model with robust standard errors, is used for estimation.

Table 3 presents the results of the polynomial and stepwise regression analyses regarding the influence of SBMI and GTI on SCP. In Model 1, only control variables are added, and R^2 is 0.0858; Model 2 adds $SBMI$ and GTI based on Model 1 and R^2 is 0.0878. Based on Model 1, Model 3 adds five polynomials ($SBMI$; GTI; $SBMI^2$; $SBMI \times GTI$; GTI^2), and R^2 increases to 0.0894. It indicates that the explanatory power of the model increases significantly after including higher-order terms, which is appropriate for polynomial regression.

Based on the polynomial regression results of Model 3, a three-dimensional surface graph that directly reflects the response surface analysis results and the two-dimensional curve graphs of the sections corresponding to the consistency line and inconsistency line are drawn in Figures 4–6, respectively. As shown in Figure 4, the consistency line

TABLE 4 Moderation effects of degree of corporate strategic aggressiveness.

	Model 4		Model 5		Model 6	
Control variables						
ln_mh	−0.0002	(0.0003)	−0.0002	(0.0003)	−0.0002	(0.0003)
ln_mss	0.0139[a]	(0.0023)	0.0141[a]	(0.0023)	0.0135[a]	(0.0023)
HHI	−0.0092	(0.0252)	−0.0094	(0.0253)	−0.0115	(0.0253)
KPMU	−0.0042[b]	(0.0021)	−0.0038[c]	(0.0021)	−0.0035[c]	(0.0021)
ln_ld	−0.0743[a]	(0.0053)	−0.0695[a]	(0.0057)	−0.0671[a]	(0.0057)
ln_fn	0.0021[a]	(0.0005)	0.0020[a]	(0.0005)	0.0019[a]	(0.0005)
LHR	0.0003	(0.0002)	0.0003	(0.0002)	0.0002	(0.0002)
EN	0.0052	(0.0080)	0.0053	(0.0080)	0.0054	(0.0080)
Independent variables						
SBMI (b_1)			0.0169[a]	(0.0058)	0.0173[a]	(0.0058)
GTI (b_2)			−0.0084	(0.0062)	−0.0082	(0.0062)
$SBMI^2$ (b_3)			0.0012	(0.0138)	−0.0005	(0.0137)
SBMI×GTI (b_4)			0.0323[b]	(0.0136)	0.0314[b]	(0.0136)
GTI^2 (b_5)			−0.0193[c]	(0.0115)	−0.0187	(0.0115)
Moderator						
STRATEGY (b_6)					0.0016[a]	(0.0005)
STRATEGY×SBMI (b_7)					0.0006	(0.0012)
STRATEGY×GTI (b_8)					0.0017	(0.0011)
$STRATEGY \times SBMI^2$ (b_9)					−0.0005	(0.0030)
STRATEGY×SBMI×GTI (b_{10})					0.0016	(0.0028)
$STRATEGY \times GTI^2$ (b_{11})					−0.0000	(0.0022)
R^2	0.0858		0.0894		0.0927	
ΔR^2					0.0033[a]	

n = 7090. Robust standard errors are shown in parentheses.
[a]$p < 0.01$.
[b]$p < 0.05$.
[c]$p < 0.1$.

is from the front (low SBMI-low GTI) to the back (high SBMI-high GTI), while the inconsistency line is from the left (low SBMI-high GTI) to the right (high SBMI-low GTI). According to the response surface analysis data of Model 3 shown in Table 4, the curvature of the response surface along the inconsistency line ($b_3 - b_4 + b_5$) is significant and negative (curvature = −0.0504, $p < 0.05$). As shown in Figure 6, the inconsistency line projected onto the response surface forms an inverted U-shaped curve. The position at both ends of the curve indicates that SBMI is inconsistent with GTI, while the middle position indicates that SBMI is consistent with GTI. The closer it is to both ends, the lower SCP is, while the closer it is to the middle, the higher SCP. It indicates that SCP is higher in firms with consistency between SBMI and GTI than in firms with inconsistency between SBMI and GTI. Therefore, to assume that Hypothesis 1 is supported. On the other hand, the slope of the response surface along the inconsistency line ($b_1 - b_2$) is significant and positive (slope = 0.0253, $p < 0.01$). Figure 6, represents the SCP on the left side (low SBMI-high GTI) of the inconsistency line is lower than that on the right side (high SBMI-low GTI), suggesting that when enterprises are faced with an inconsistency between SBMI and GTI, the combination of low SBMI-high GTI will lead to lower SCP compared to the combination of high SBMI-low GTI. Therefore, it supported Hypothesis 2.

The results of Model 5 and Model 6 in Table 4 show that R^2 increases by adding the interaction terms between the moderator and each of the five terms in the benchmark polynomial regression equation ($\Delta R^2 = 0.0033$, $p < 0.01$).

This result indicates that the degree of corporate strategic aggressiveness moderates the relationship between SBMI-GTI inconsistency and SCP. The three-dimensional surface graphs directly reflect the polynomial regression results with a high degree of strategic aggressiveness and a low degree of strategic aggressiveness in Figures 7, 8, respectively. To more clearly identify the moderating effect of the degree of strategic aggressiveness on the relationship

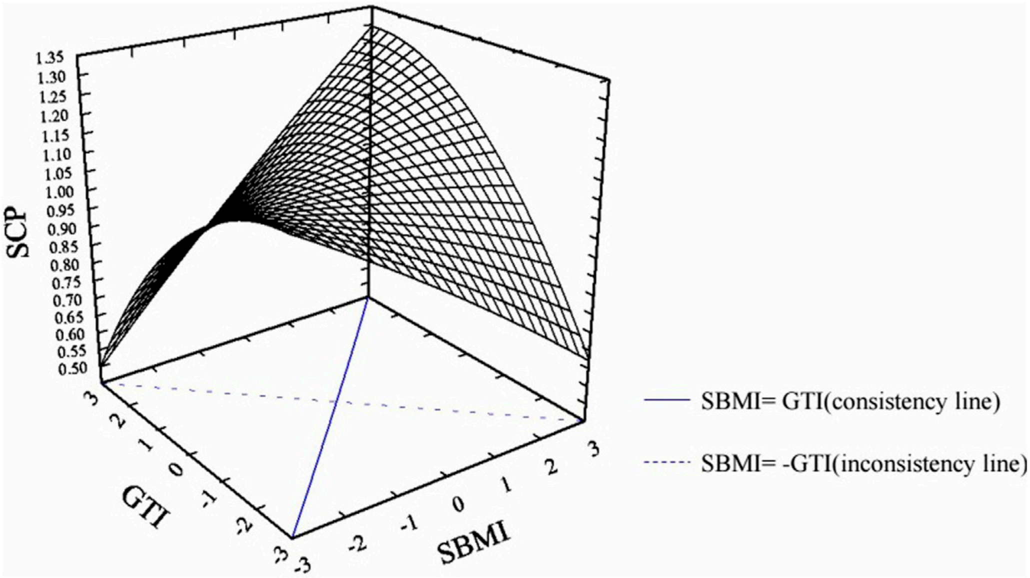

FIGURE 7
Surface graph of SBMI-GTI consistency/inconsistency on SCP, when the degree of corporate strategic aggressive is high.

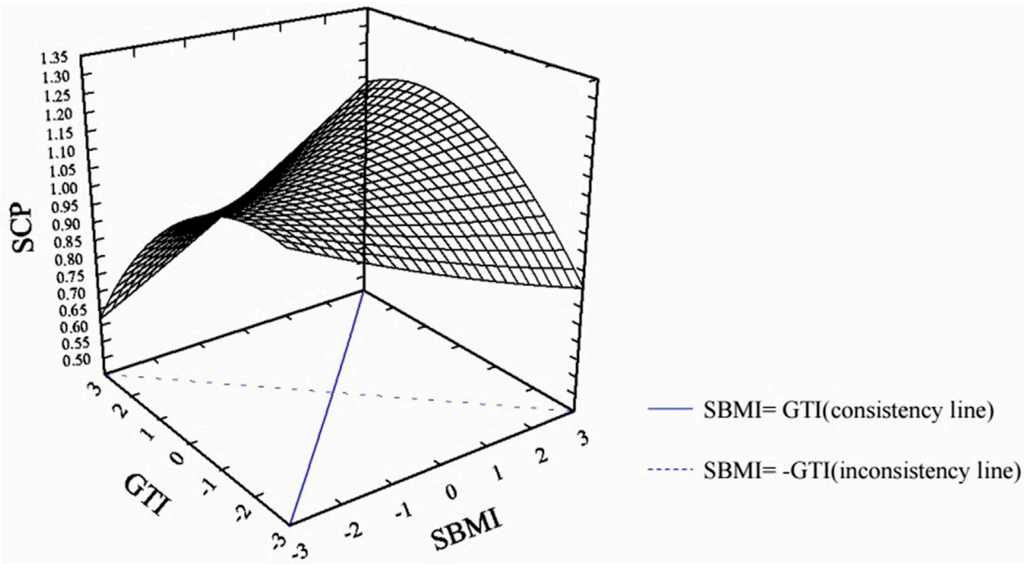

FIGURE 8
Surface graph of SBMI-GTI consistency/inconsistency on SCP, when the degree of corporate strategic aggressive is low.

between SBMI-GTI inconsistency and SCP of a firm, we also provide the side views of response surfaces along the inconsistency line ($M \pm 1SD$) in Figure 9. Compared to a low degree of strategic aggressiveness, a high degree of strategic aggressiveness makes the curvature of the blue inverted U-shaped curve greater and more pronounced in Figure 9. When SBMI is more consistent with GTI, the level of SCP is higher; when SBMI is less consistent with GTI, the level of SCP is lower. A high degree of corporate strategic aggressiveness amplifies the effect of the SBMI-GTI combination on SCP. Therefore, it supports Hypothesis 3.

5.3 Robustness test

To further ensure the reliability of the study findings, the following robustness tests are applied. In Table 5, the dependent variable SCP is treated with a lag of one period, and the results of the benchmark regression and moderating effect results are shown in columns RO-1a and RO-1b. Second, replace the proxy for the independent variable with more stringent green invention patents granted to measure GTI, and the benchmark regression and moderating effect results are in Table 5, columns RO-2a and RO-2b. Finally, for estimation, a fixed

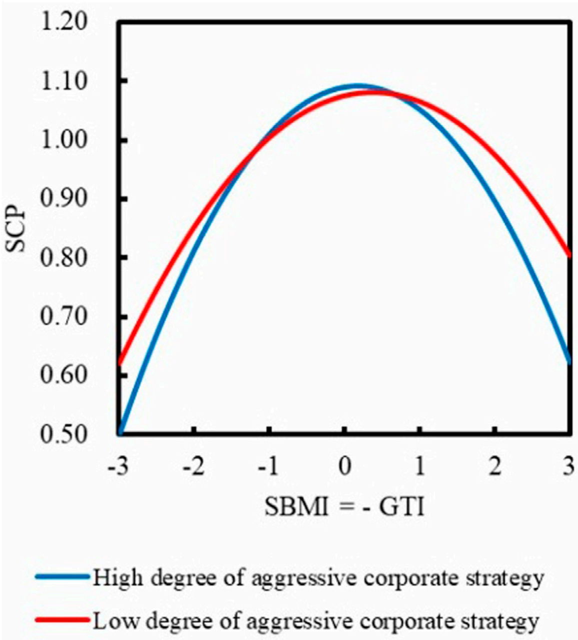

FIGURE 9
Side view of response surface along inconsistency line with the moderating effect.

effects model with Driscoll-Kraay standard error correction is used, and the benchmark regression and moderating effects results are shown in Table 5, columns RO-3a and RO-3b.

The polynomial regression analysis and robustness test results all remain consistent with the previous, indicating that the results of this paper are not affected by variable measurement or estimation methods, and the findings are highly robust.

6 Discussion and conclusion

6.1 Summary results

The impact of the interaction between SBMI and GTI on SCP is investigated using a sample of 1468 Chinese A-share listed manufacturing enterprises and the "sustainable dual innovation perspective."

According to the empirical findings, in the consistent state of SBMI and GTI, SCP is higher than the inconsistency between SBMI and GTI. SBMI and GTI have natural synergies, and their influence on SCP has a matching effect. When the inconsistency between SBMI and GTI increases in either direction, the level of SCP decreases, indicating that sustainable corporate development requires both the pull of SBMI and the push of GTI. SBMI and GTI have a usual synergy, and as a result, they have matching effects on SCP.

Second, to fully understand the complex interactions between SBMI and GTI, it also reveals the specific impact of the inconsistency between SBMI and GTI on SCP. It is found that SCP levels are significantly higher when firms choose the high SBMI-low GTI combination than the low SBMI-high GTI. These findings suggest that the high SBMI-low GTI combination is perceived as more valuable for sustainable growth and is preferred by most businesses, whereas the low SBMI-high GTI combination may introduce more "disruptive factors." It is a fascinating and significant finding from this study.

Third, using the degree of strategic aggressiveness as the moderator variable, the study's findings show that the inverted U-shaped curve is more curved under the strategic conditions of firms with a high degree of aggressiveness than firms with a smaller extent of aggressiveness. It suggests that a high degree of corporate strategic aggressiveness amplifies the effect of SBMI-GTI inconsistency on SCP; the more inconsistent the SBMI-GTI combination, the lower the SCP. A low degree of aggressiveness moderates this effect. The more inconsistent the SBMI-GTI combination is, the less degree of corporate strategic aggressiveness leads to a slightly higher SCP than a lower one. SBMI-GTI tends to be consistent, a low degree of corporate strategic aggressiveness drives SBMI-GTI to produce a higher SCP. According to the findings, the degree of corporate strategic aggressiveness increases the impact of the SBMI and GTI combination on SCP.

6.2 Theoretical contribution

This paper develops four significant contributions to the existing literature.

First, prior research has only looked at the effects of SBMI or GTI on SCP separately, using a degree of separation and opposition treatment. However, later researchers have talked about how BMI and GTI can be coordinated to improve organizational performance (Kaiyuan et al., 2019; Qu et al., 2021; Tong et al., 2022), no quantitative investigation of the specific impact of the interaction between SBMI and GTI on SCP. This is the first study to incorporate both SBMI and GTI into a theoretical framework to investigate the effect of their interaction on SCP.

Second, the study confirms that promoting sustainable enterprise development requires both SBMI and GTI. SBMI and GTI are naturally complementary, and their impact on SCP has a matching effect. It also characterizes between high SBMI-low GTI and low SBMI-high GTI, with low SBMI-high GTI causing more negative to SCP than high SBMI-low GTI. Companies prefer high SBMI-low GTI combinations to improve their sustainability. Provide a theoretical explanation as well.

Third, a continuum model of the degree of corporate strategic aggressiveness drawing on Miles and Snow's (1978, 2003) strategy classification method is used as an analytical framework to confirm that highly aggressive corporate strategies increase the impact of SBMI-GTI inconsistency on SCP. A firm strategy with a high degree of aggressiveness results in a higher SCP. SBMI and GTI confirm that the degree of corporate strategic aggressiveness has an "amplifying effect" on SCP. This adds to the body of knowledge on the corporate strategy's moderating impact on the causal mechanism of the interaction between SBMI and GTI on SCP; it also offers sound theoretical guidance for businesses deciding on their future innovation strategies. Finally, polynomial regression is used with response surface analysis as a novel research method. Although measurement methods such as difference value (Cao et al., 2009), sum value (Lubatkin et al., 2006), and product value (Shu et al., 2015) have been used to explain the consistency and inconsistency between two associated variables, such methods cannot effectively reveal the impact of the difference in direction between SBMI and GTI on SCP. Polynomial regression can

TABLE 5 Results of robustness test.

	RO-1a	RO-1b	RO-2a	RO-2b	RO-3a	RO-3b
Control variables						
ln_mh	0.0003	0.0003	−0.0002	−0.0002	−0.0002	−0.0002
	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0002)	(0.0002)
ln_mss	0.0160[a]	0.0156[a]	0.0139[a]	0.0132[a]	0.0141[a]	0.0135[a]
	(0.0030)	(0.0030)	(0.0023)	(0.0023)	(0.0027)	(0.0026)
HHI	−0.0600[b]	−0.0604[b]	−0.0121	−0.0142	−0.0094	−0.0115
	(0.0275)	(0.0275)	(0.0250)	(0.0250)	(0.0231)	(0.0230)
KPMU	−0.0018	−0.0014	−0.0038[c]	−0.0036[c]	−0.0038	−0.0035
	(0.0026)	(0.0026)	(0.0021)	(0.0022)	(0.0040)	(0.0040)
ln_ld	−0.0908[a]	−0.0897[a]	−0.0698[a]	−0.0676[a]	−0.0695[a]	−0.0671[a]
	(0.0085)	(0.0084)	(0.0057)	(0.0057)	(0.0128)	(0.0124)
ln_fn	−0.0002	−0.0003	0.0021[a]	0.0020[a]	0.0020[b]	0.0019[b]
	(0.0006)	(0.0006)	(0.0005)	(0.0005)	(0.0008)	(0.0008)
LHR	−0.0000	−0.0001	0.0003	0.0002	0.0003[b]	0.0002[c]
	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0001)	(0.0001)
EN	0.0102	0.0105	0.0053	0.0058	0.0053	0.0054
	(0.0103)	(0.0100)	(0.0079)	(0.0079)	(0.0046)	(0.0044)
Independent variables						
SBMI (b_1)	0.0330[a]	0.0323[a]	0.0225[a]	0.0228[a]	0.0169	0.0173
	(0.0076)	(0.0075)	(0.0068)	(0.0067)	(0.0134)	(0.0134)
GTI (b_2)	−0.0016	−0.0017	−0.0131[c]	−0.0115	−0.0084[b]	−0.0082[b]
	(0.0072)	(0.0072)	(0.0071)	(0.0071)	(0.0032)	(0.0028)
$SBMI^2$ (b_3)	−0.0021	−0.0049	0.0010	−0.0013	0.0012	−0.0005
	(0.0188)	(0.0186)	(0.0140)	(0.0139)	(0.0151)	(0.0146)
SBMI × *GTI* (b_4)	0.0444[b]	0.0445[a]	0.0322[b]	0.0319[b]	0.0323[a]	0.0314[b]
	(0.0184)	(0.0179)	(0.0152)	(0.0150)	(0.0097)	(0.0097)
GTI^2 (b_5)	−0.0196	−0.0199	−0.0163	−0.0151	−0.0193[c]	−0.0187[c]
	(0.0132)	(0.0131)	(0.0148)	(0.0146)	(0.0099)	(0.0101)
Moderator						
STRATEGY (b_6)		0.0004		0.0019[a]		0.0016[a]
		(0.0007)		(0.0006)		(0.0004)
STRATEGY × *SBMI* (b_7)		0.0003		−0.0001		0.0006
		(0.0016)		(0.0015)		(0.0007)
STRATEGY×*GTI* (b_8)		−0.0018		0.0012		0.0017[c]
		(0.0014)		(0.0013)		(0.0008)
STRATEGY×$SBMI^2$ (b_9)		0.0095[b]		−0.0003		−0.0005
		(0.0044)		(0.0030)		(0.0022)
STRATEGY×*SBMI*×*GTI* (b_{10})		−0.0115[a]		−0.0005		0.0016
		(0.0040)		(0.0033)		(0.0011)

(Continued on following page)

TABLE 5 (*Continued*) Results of robustness test.

	RO-1a	RO-1b	RO-2a	RO-2b	RO-3a	RO-3b
STRATEGY×GTI² (b_{11})		0.0012		−0.0015		−0.0000
		(0.0026)		(0.0028)		(0.0009)
Response surface analysis						
Congruence line: SBMI = GTI						
Slope (b_1+b_2)	0.0315[a]		0.0094		0.0091	
	(0.0113)		(0.0100)		(0.0149)	
Curvature (b_3+b_4+b_5)	0.0226		0.0170		0.0122	
	(0.0269)		(0.0217)		(0.0161)	
Incongruence line: SBMI = −GTI						
Slope (b_1-b_2)	0.0346[a]		0.0356[a]		0.0255[c]	
	(0.0096)		(0.0096)		(0.0124)	
Curvature (b_3-b_4+b_5)	−0.0661[b]		−0.0475[c]		−0.0507[b]	
	(0.0316)		(0.0286)		(0.0205)	
N	5235	5235	7090	7090	7090	7090
R^2	0.1012	0.1065	0.0897	0.0932	0.0894	0.0927
ΔR^2		0.0053[a]		0.0035[a]		0.0033[a]

Robust standard errors are shown in parentheses.
[a]$p < 0.01$.
[b]$p < 0.05$.
[c]$p < 0.1$.

provide a strong explanation for the difference scores (Edwards and Parry, 1993; Edwards and Cable, 2009) between SBMI and GTI consistent and inconsistent, high SBMI-low GTI and low SBMI-high GTI. The response surface analysis method, in particular, can visualize the above empirical results, which can assist in comprehending the specific impact of different SBMI and GTI combinations on SCP. This research method is rare in panel data studies of the relationship between SBMI, GTI, and SCP, and this study makes a significant theoretical attempt.

6.3 Management implications

Based on the research presented above, the following management implications are drawn:

The preliminary results indicate that maintaining the SBMI and GTI pace will improve performance. Because when SBMI and GTI align, SBMI creates a sustainable business plan for green products before they are fully grown in GTI; at the same time, SBMI assists GTI in determining the next stage of development. SBMI is protected to some extent throughout the development of GTI by increasing the competitiveness of green product differentiation. Although SBMI and GTI may evolve recursively, a trade-off situation should be avoided as much as possible. The SBMI and GTI must consider both and walk as balanced as possible on two legs.

Second, the results show that high SBMI-low GTI is more valuable in the short term and has indeed become the preferred choice for most enterprises, even though the significant risk of GTI does not assure business success (Hirshleifer et al., 2012; Wicki and Hansen, 2019; Wang et al., 2022). Due to resource limitations, most businesses are now paying closer attention to combinations with high SBMI and low GTI. However, these companies are concerned with short-term gains and have to abandon their long-term goals. GTI is the primary source of long-term corporate performance. It also suggests that SBMI should eventually convert GTI to avoid SBMI suspiciously communicating sustainability efforts.

Finally, findings suggest that a high degree of corporate strategic aggressiveness modifies the specific effects of the SBMI-GTI combination on SCP by "amplifying." Therefore, in the process of promoting SBMI and GTI, companies should focus on "open source" rather than "cost-cutting," recruit marketing and R&D talents, adopt complex coordination mechanisms across departments and fields (Sun et al., 2017), develop and maintain a broad and continuous development of technology and market environment insight ability (Anim et al., 2018), and respond quickly to demand the world's future.

6.4 Limitations and future directions

The main limitations of this paper are as follows: first, Chinese manufacturing companies have made remarkable innovation achievements in the last decade, so here chose panel data of Chinese manufacturing listed companies for 2010–2020 to reveal the impact of SBMI and GTI on SCP. However, in comparison to SBMI, GTI is more of a system project that takes a long time and has a slow effect. Moreover, the effect of the SBMI-GTI combination on SCP has some more novel findings in a larger study and time interval. Future studies may consider stretching the study time scale forward or backwards to investigate the causal mechanisms between the abovementioned variables. Second, this study does not explicitly examine the differences in enterprise ownership among the research objects. Because SOEs bear more social responsibility in promoting sustainable development, the SBMI-GTI SOE combination should have some unique characteristics. For example, do SOEs balance SBMI and GTI as a typical demonstration function in transitioning to a sustainable development model? SOEs' inherent disadvantages in terms of institutional mechanisms and other aspects result in inefficiencies and investment distortion effects for long-term development?

Future research could provide some useful insights into this area. Finally, most scholars have adopted ROA as a proxy variable for corporate financial performance, even though it can reflect an enterprise's financial status and operating results in a given period. However, explanations for enterprises' solvency, growth, operating capacity, and equity expansion capacity remain insufficient. Therefore, future research is establishing an index system to measure corporate financial performance.

Data availability statement

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

Author contributions

NZ: Conceptualization, Visualization, Writing—review and editing. LP: Writing—review and editing. YT: Methodology, Data curation, Software, Writing—original draft, Writing—review and editing. XC: Visualization, Supervision, Validation, Writing -review and editing. NZ: Methodology, Data curation. JG: Formal analysis, Data curation. All authors have read and agreed to the published version of the manuscript.

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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.

Publisher's note

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Determining factors in shaping the sustainable behavior of the generation Z consumer

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Introduction: Organizations currently emphasize green marketing strategies by implementing marketing practices, aiming to design, produce, promote and sell green products. Thus, both consumers and producers have turned their attention to the category of environmental friendly products, taking into account that the concept of green marketing is now being given greater importance. Responsible organizations have begun to adapt their strategies in production, promotion and interaction activities with consumers or potential consumers of organic products in the context we are going through, when environmental protection becomes an imperative. Analysis of the sustainable behavior of Generation Z is a determining factor from the perspective of the task that this generation will naturally take on, in terms of environmental responsibility.

Methods: The research aims to determine the profile of the Generation Z consumer, in order to adapt the strategic actions of the government or organizations to direct and educate as objectively and efficiently as possible towards adopting the principles of ecological, sustainable and responsible consumption. Based on the data collected through a survey, we analyzed the sustainable behavior of Generation Z consumers studying at Romanian universities where there are specializations in this field. The research is quantitative, using structural equation modelling with partial least squares (PLSSEM) to test the hypotheses regarding the relationship between the determining factors and the sustainable behavior of Generation Z consumers.

Results and Discussion: The results show that there is a positive relationship between both the sustainable behavior of Generation Z consumers and the satisfaction it conveys to them, as well as their environmental protection activities. However, there is no relationship between the sustainable behavior of Generation Z consumers and the green marketing practices of the organizations, environmental issues and their identification with the environmentally responsible consumer.

KEYWORDS

green marketing practices, green products, green behaviour, generation Z, sustainability, environmental protection

1 Introduction

The activity of Green Marketing (GMk) has a relatively recent history in the consumers' perception and consciousness, in many cases the real evaluation of this concept causes confusion regarding its meaning. Thus, the implementation of GMk principles emerged in the 1970s from the need to educate the consumer towards a mindset favoring responsible consumption and environmental protection by adopting specific measures (Andronie et al., 2019). Among the first definitions of this concept, we can see an approach to the field from both a positive and negative perspective, showing that there are activities which contribute to the environmental pollution, consumption of energy resources, but also non-energy resources (Polonsky, 2011). GMk was defined as a complex product including improvement activities, pricing strategies, promotion policies and distribution methods which do not harm the environment (Saha and Darnton, 2005), instead, through the activity of product marketing, are safe for the environment (Xie et al., 2015).

In this context, GMk goes beyond the simple promotion of products or services with a green component. It is considered a field which has been long-researched but still insufficiently understood, and the possibility that this marketing concept can make a relevant and impactful contribution to society brings the need to focus more on major changes in thinking and practice (Peattie and Crane, 2005).

The mission to concretely define what GMk represents takes into account the numerous perceptions reflected in the literature. One understanding is that GMk sums up a wide range of processes, including product modification, production stages, packaging and promotion (Polonsky, 1994). In direct proportion to the importance given to the care of environmental sustainability, over time, the understandings regarding the approach to the concept of GMk have been very different (Dangelico and Vocalelli, 2017). Thus, the emphasis was placed on GMk policies which helped companies to identify new market niches and new consumer segments, by incorporating new visions and trends into their marketing process and strategy. In this context, organizations increasingly focused on the segment of green consumers, namely the consumers concerned with environmental protection and their own health (Pavan and Payal, 2012). In addition, because people are more and more willing to invest in the purchase of green products, the market includes them more (Ștefănică et al., 2020). The various objective reasons for this type of behavior relate to the concern for one's own health, responsibility towards the environment and towards other people, the increasingly varied knowledge which consumers begin to acquire either through their own research in the market or in specialized publications, or through media channels, other categories of consumers or other sources of information.

In the current activity of manufacturers or service providers, GMk can bring safe and long-term benefits, at the cost of observing the principles of quality management, primarily by being oriented to the customers and their needs. During the process of customer loyalty, in addition to the production and service delivery process, the provider manages to carry out an activity of education of the beneficiaries, by offering advantageous alternatives in terms of method, procurement time, method of use or price. Consequently, GMk is a concept which we meet both in the case of consumer and industrial goods, and we also find it in the service area, when more and more destinations try to promote themselves through activities provided to customers with a very small negative environmental impact, such as ecotourism (May 1991; Troumbis, 1991). Research shows that GMk brings with it particularities in behavior or purchasing intention, the actual purchasing behavior in the case of green products being influenced by a multitude of factors (Groening et al., 2018).

Generation Z and their behavioral patterns regarding the purchasing and consumption of green products according to gender have been insufficiently addressed as a main theme in specialized analyses. The literature review shows that there are experimental studies indicating major differences between the ways of making purchasing decisions in women and men (Yang and Wu, 2007), or differences among men of different generations (Brosdahl and Carpenter, 2011). The field of purchasing behavior for Generation Z representatives lacks analyses to show significant details or validated studies, especially since this category of consumers have different purchasing styles compared to past generations. In this context, in-depth research is needed, an aspect also substantiated by Bakewell and Mitchell (2003), who pointed out the research gaps in this direction and the need to start and support them. Therefore, this study aims to bring more information in the field of GMk, especially since it is focused on an analysis of the factors highlighting the purchasing differences of Generation Z consumers for green products.

Considering the issue analyzed, this paper is organized in the following sections: introduction, literature review and development of research hypotheses, research methodology, results, discussions and conclusions.

2 Theories and hypotheses

2.1 Green marketing practices and generation Z consumers

In recent years, GMk has occupied an increasingly extensive field in the practice of organizations and in the research fields of specialists due to the need for awareness of the importance which environmental practices should have in the strategy of organizations (Mukonza et al., 2021). The trend in the intentions of orientation towards the GMk activity of the organizations is to increase and integrate the vast activity into the overall management strategy. The promotion and practice of green consumerism can be supported by including in the strategy the relevance of sustainability and eco-innovations in this sector (Sarkar, 2012). Currently, a real promoter of GMk culture is Generation Z, which is at an intersection of decisions regarding GMk practices, not having a relevant benchmark in previous generations and being the actual generation with responsible behavior regarding environmental protection.

Considering that Generation Z is represented by the category of individuals born in the period 1990–2000, who from the point of view of their inclusion belong to a certain typology of consumers, they present obvious particularities, derived from the periods they crossed. These particularities are very well reflected in the purchasing behavior and the attitude towards specific concepts, in general, behavior marked by the following characteristics: the intention to innovate, the need for convenience, the search for security of any type and manifestations of escape from previous customs (Wood, 2013). Generation Z has also been called the Post-Millennial Generation (born between 1997–2012) (Loria, 2018) or IGen (Bromwich, 2018). This generation is considered the engine of innovation and change, being a huge challenge for the marketing of any organization (Wood, 2013; Morgan, 2016).

The representatives of Generation Z consumers are generally more informed, and in particular, analyzing their degree of information in relation to the concepts of GMk and Green Marketing Practices (GMkP), it is obvious that there is a balance of the weights held by the information regarding GMk and GMkP, with advantageous fluctuations in certain periods for GMk. The explanation is easily observable and deductive from considerations related to age characteristics: the use of technology, the influence of the media, of social networks, the responsible behavior which young people take from those around them but without updating the information directly, and consequently, in certain circumstances, GMkP are not known, implicitly adopted, in their entirety (Bhavana and Thiruchanuru, 2018).

Generation Z consumers are characterized by the tendency to avoid the agglomeration of information, by focusing not only on the factors concerning them directly, the lack of time or experience, they are focused more than other generations on the concepts of green, sustainable, ecological, and have several social and ecological objectives (Kılıç et al., 2021). Thus, experienced retailers can use prospects or actual consumers as a competitive advantage in capturing representatives of Generation Z, capitalizing on the attributes of this generation, one of the most important being the interest and access to technology (Dospinescu et al., 2019). Consumer training can be done through smart sale applications, through which young people can be informed in making correct purchasing decisions (Priporas et al., 2017). The young people of Generation Z grew up in an environment where the population was aware of the importance of environmental responsibility, with school hours specifically allocated to this subject and with natural recycling skills, perspectives predicting a strict future approach to this generation regarding GMk and GMkP (Líšková et al., 2016).

Generation Z is assaulted daily in this information age we are going through by diverse pieces of information, coming from all environments, sometimes difficult to filter from the point of view of importance, which is why the concept of GMk is part of the category of notions which need to be explained, and later correctly understood by young people (Tamer and Popescu, 2016). Generation Z consumers inform themselves and are also informed about the concepts of GMk and GMkP, as they are an integral part of marketing and communication strategies of the companies. Generation Z is a generation formed in the context of the large-scale existence of environmental practices and is aware of environmental threats and their effects, being aware of the concepts of GMk and GMkP since primary school (Lerch, 2020). Attitudes related to green marketing are a natural component of the daily life of Generation Z, namely through recycling activities, use of energy efficient devices, purchase of environmental friendly products and food.

According to this dimension resulted from the literature, the research hypothesis tested in our study is the following:

Hypothesis 1 (H1): There is a direct and significant relationship between the GMkP of organizations and the sustainable behavior of Generation Z consumers.

2.2 The attitude of generation Z consumers towards environmental protection under the influence of GMkP

Currently, GMkP have become a constant and a normality of our life, representing a tool to protect the environment. Consumers have become much more informed, advised through the campaigns of the organizations, and they are willing to allocate a larger budget for the purchase of green products. In this context, GMk creates new markets and implicitly new jobs (Yazdanifard and Mercy, 2011). Thus, GMkP transposed into company activities, including through their reflection in activities aimed at corporate social responsibility (CSR), later become practices assimilated by the population. Environmental protection is promoted by the efforts of the companies to produce, promote, distribute and price a product or service in accordance with GMkP (Polonsky, 2011). The way in which green marketing was promoted over time consisted of multiple improvements, practices or innovations, which were subsequently brought to the attention of customers or potential customers (Cherian and Jacob, 2012). These green practices consisted in processes, promotion, branding and communication activities, packaging, and supply chain, all fitted to protect the environment. Through these measures, consumers implemented GMk measures in their purchasing and consumption behaviour, and implicitly in environmental protection (Suki and Suki, 2019).

Nguyen's research (2021) illustrates the opposite of what was mentioned above, stating that there are representatives of Generation Z who are not influenced by GMkP measures adopted by companies, therefore, the intention to purchase green products is very rare, random or absent.

According to the source of information and the manner of transmission of information regarding GMkP of the organizations, the attitude and behavior of Generation Z consumers regarding the active assimilation of these practices may vary as a form of manifestation. There are effective strategies for GMkP communication in the organizations, compatible with the profile of Generation Z representatives, as well as less inspired channels through which this information is attempted to be transmitted. Sometimes companies fail to convey enough information through their own campaigns regarding the way in which the products or services offered are compatible with the consumer's vision of environmental protection. Generation Z exponents are also strongly influenced by the reputation of a company, by the information available on product packaging, by the use of symbols and specific terminology (Smith and Brower, 2012). Nadanyiová and Gajanová (2018) identified the benefits of organizations using green marketing principles and communicating them through multiple channels of information. According to this study, among all the age groups, Generation Z is the most interested category in getting involved in activities to protect the environment, an initiative which confirms the fact that organizations use effective channels or sources to transmit information about GMkP. They positively shaped the trend of millennials' involvement in the purchase of green products and involvement in activities of environmental protection by saving water, energy and by recycling.

Consequently, we can see that Generation Z has particularities in terms of consumption behavior, the choice of green products, principles or particular reasoning compared to other generations, so that both manufacturers and retailers take these aspects into

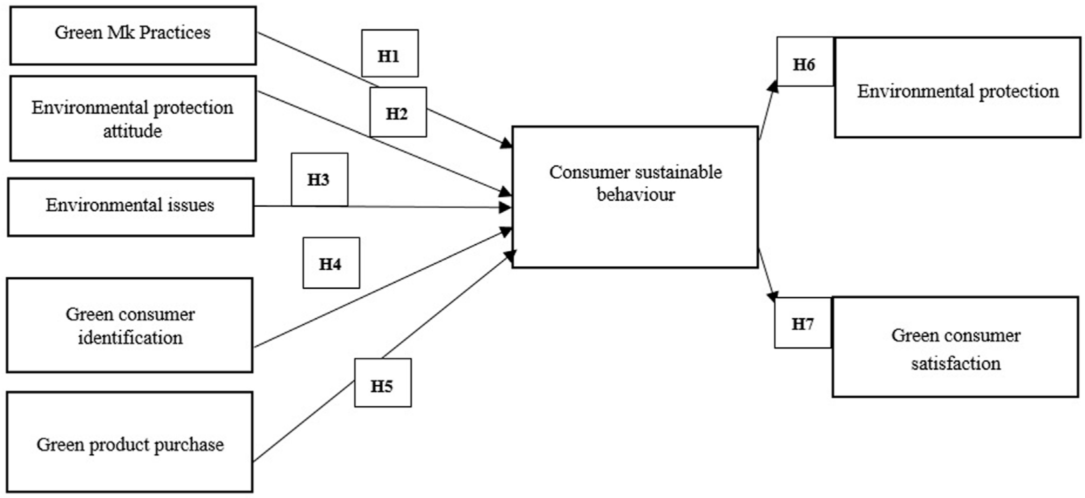

FIGURE 1
Theoretical model regardingthe green consumer's profile.

account when choosing their own GMkP. In this context, there is a certain generational approach, often used in the development, promotion and sale of this particular category of products, i.e., green products (Dabija et al., 2020). GMkP are a support tool in choosing and maintaining consumption habits, but they can also be a determining factor of environmental protection activities or of the choice of green products. Studies indicate changes in the attitude and behavior of Generation Z, who, unlike the generation before them, seems to be oriented towards a behavior with a tendency to stability, both in terms of choosing a job and in terms of habits (Reiners, 2020). Thus, we can state that nowadays the GMkP of organizations, including related products or services, are much easier to transmit and receive by Generation Z consumers, because, as the existing research proves, this generation is the first to naturally realize the importance of the environment, of specific consumption, of adopting a certain behavior or type of consumption, which encourages companies to insist on the implementation of specific green marketing practices (Naidu et al., 2020).

Moreover, Generation Z is the first generation born and raised in the era of technological development, focused on digital components and with a strong identity belonging to technology (Singh and Dangmei, 2016), a generation who will bring multiple changes, including on the labor market. The distinct style of behavior, attitudes, preferences, reactions to the marketing moves of the companies regarding green practices are diametrically opposed to those of the previous generation. Compared to Generation Y, Generation Z seems to be less motivated by the financial component or by marketing strategies involving discounts, promotions, sales, instead emphasizing quality (Schawbel, 2014). For this reason, a campaign tailored to the behavioral characteristics of this generation can be successful, having the advantage of being directed towards an informed, pragmatic generation oriented towards a high quality of life.

According to this dimension resulted from the literature, the research hypothesis tested in our study is the following:

Hypothesis 2 (H2): There is a direct and significant relationship between the environmental protection attitude and the sustainable behavior of Generation Z consumers.

2.3 Generation Z consumers' perceptions of environmental issues

Environmental issues are a significant source of concern for many people around the world (Ştefănică et al., 2020), regardless of the consumer generation they belong to. Among them, for the representatives of Generation Z, climate change, pollution or loss of natural resources are at the top of the list of vital challenges of our time (Barbiroglio, 2019), which led them to mobilize and organize school strikes by which young people demanded specific actions to improve environmental problems. According to the results of the research conducted by Kamenidou et al. (2019), global warming and air pollution seem to be the most pressing problems, because they can lead to the extinction of species or the appearance of serious diseases. In this sense, there are recent studies (Bailey et al., 2022; Schwartz et al., 2022) linking environmental events such as temperature extremes, air pollution, flooding, and sea level rise to various mental health issues, including difficulties in social relationships, anxiety, depression (Reyes et al., 2021), recorded especially among young people. Air pollution and food safety concerns increased also the awareness of environmental issues for Generation Z consumers in Taiwan (Chen et al., 2018). Contrary to the results of previous research works, which demonstrate that the youth of Generation Z are aware of the seriousness of environmental issues and their influence on consumption, a study conducted by Jürkenbeck et al. (2021) divides this cohort into three different segments in terms of climate change awareness. However, the results show that of the nearly 1500 young people included in the sample, half are very aware of climate change, nearly 30% recognize climate change, but consider that the risks are relatively low, while 13.90% of respondents deny the existence of climate change.

TABLE 1 Respondents' characteristics.

Classification	Description	Frequency	
		Total	Percentage
Gender	Female	561	71.56%
	Male	223	28.44%
Environment	Rural	365	46.56%
	Urban	419	53.44%
Age	(18–29)	784	100,00%
Personal income	under 1000 RON	310	39.54%
	between 1000–2000 RON	175	22.32%
	between 2000–4000 RON	204	26.02%
	between 4000–6000 RON	70	8.93%
	over 6000 RON	25	3.19%
Family income	under 2000 RON	114	14.54%
	between 2000–4000 RON	259	33.04%
	between 4000–6000 RON	215	27.42%
	between 6000–10000 RON	142	18.11%
	over 10000 RON	54	6,89%

Source: authors' calculations based on Stata statistical analysis software.

According to Singh and Dangmei (2016), Generation Z consumers are very concerned about environmental issues, very aware of looming shortages, indicating that they have a high degree of responsibility towards natural resources. Hidayat and Hidayat (2021) mention that the majority of Generation Z shows deep concern about the negative implications of a development which exploits nature, unbalanced ecosystems and human ignorance of environmental sustainability. Generation Z consumers are more willing than older generations to engage in environmental activism, such as volunteering and donating money to environmental causes.

In order to meet the demands of Generation Z consumers, companies will need to adapt their green marketing strategies to fulfil consumers' sustainability expectations, considering that this group of consumners is much more informed than the other generations, with more knowledge about sustainability and concerned about environmental issues, willing to pay more for green products, implicitly organic, healthier food (Su et al., 2019).

According to this dimension resulted from the literature, the research hypothesis tested in our study is the following:

Hypothesis 3 (H3): There is a direct and significant relationship between the perception of environmental issues and the sustainable behavior of Generation Z consumers.

2.4 Identification of generation Z with the green consumer

According to specialized studies, consumers of environmental friendly products have their own, separate characteristics compared to non-consumers of green products. Generations X and Z seem to be much more concerned with everything related to green consumption, the practices of manufacturing companies or traders influence the attitude and size of consumption (Bhavana and Thiruchanuru, 2018). GMkP mainly include green marketing strategy, communication and promotion channels, price and quality offered. Regarding the gender-related consumption behaviors, specialists state that there are major differences in terms of attitude, purchasing and consumption behavior between men and women, influenced by marketing practices. Women consciously buy and consume green products more than men, they are receptive to recommendations coming from people they know or from marketing practices of organizations ((Zhao et al., 2021)). At the same time, Generation Z is guided and oriented towards everything that means the digital age, preferring online payments instead of printed invoices, they do not approve of waste, and they are willing to pay extra for the purchase of green products (Ahmad and Omar, 2018). Green advertising captures buyers emotionally, and the purchasing decision process in the case of female consumers from Generation Z is influenced to a greater extent than in the case of male consumers, preferring green products, their labelling, the information presented on the product packaging, and their recyclable quality (Narula and Sabharwal, 2016).

Generation Z values quality more than previous generations. Most of the time, this group of consumers makes purchases based on their own beliefs and marketers start to earn their trust and loyalty as early as possible. Studies indicate that the women from this generation are the ones who purchase goods or services for the most part and marketing strategies are more focused on this aspect (Williams and Page, 2011). In addition, individual behavior is not always correlated with their perception of environmental components or green consumption, the latter being negative, in most cases discrepant with personal perceptions of the concepts as a whole (Deliana and Rum, 2019). Generation Z is an informed, practical generation, oriented towards healthy consumption, and in terms of gender differences in the purchasing process, the female gender outranks, both in terms of consumption and the orientation towards purchasing green products, men being less interested than women in the environment and implicitly in such products (Diamantopoulos et al., 2003).

Some research works demonstrate that women are more attentive to environmental issues, purchasing and consumption of green products (Campbell-Arvai et al., 2012; Kamenidou et al., 2019), also local green products, from moral, ethical and economic considerations and factors (Bumbac et al., 2020). Generation Z avoids the waste of green food, compared to previous generations, and in terms of gender differences and sustainable consumption behavior, research works confirm the hypothesis that women show a greater degree of rational, responsible consumption of green products than men, having concerns and tendencies to reuse or recycle more (Bulut et al., 2017). Another research found significant gender differences in relation to the perception of Generation Z consumers according to gender, and this time there were higher percentages of women regarding the attitude and consistency of the act of purchasing (Lorincová et al., 2019). In conclusion, although the purchasing power of Generation Z exceeds that of Generation Y, the rational consumption of the first, makes them allocate a smaller budget to expenses, a situation also reflected in the case of purchasing green products (Kowalska et al., 2021).

According to this dimension resulted from the literature, the research hypothesis tested in our study is the following:

Hypothesis 4 (H4): There is a direct and significant relationship between the degree of identification with the green consumer and the sustainable behavior of Generation Z consumers.

TABLE 2 Results of descriptive statistics.

	Constructor	Mean	Category
	PGMk - Green Marketing Practices	6.28	Totally agree
	APM - Environmental protection attitude	5.82	Generally agree
	PM - Environmental issues	6.30	Totally agree
	CV - Green consumer identification	4.65	Partly agree
	APE - Green product purchase	5.48	Generally agree
	CPE - Sustainable consumer behaviour	5.29	Partly agree
	IPM - Environmental protection	5.38	Generally agree
	SCV - Green consumer satisfaction	5.79	Generally agree

Item	Item names	Mean	Median	Mode	Std. Deviation
PGMk1	Manufacturing green products	6.35	7	7	1.082
PGMk2	Manufacturing products through a green process	6.35	7	7	1.029
PGMk3	Promotion of products through green communication methods	6.18	7	7	1.132
PGMk4	Product branding associated with green marketing practices	6.09	7	7	1.178
PGMk5	Modification of products to make them green	6.14	7	7	1.260
PGMk6	Changing product packaging to suit the environment	6.32	7	7	1.158
PGMk7	Educating the customer to use the products in a green way	6.48	7	7	1.028
PGMk8	Using green supply chain for procurement and distribution	6.31	7	7	1.108
APM1	It is important to me that the products I use do not harm the environment	6.10	6	7	1.270
APM2	I consider the potential environmental impact of my activities when making many of my decisions	5.77	6	6	1.262
APM3	My purchasing habits are affected by my concern for environmental protection	5.23	5	6	1.381
APM4	I am concerned about the waste of our planet's resources	6.18	7	7	1.259
APM5	I would describe myself as environmentally responsible	5.82	6	7	1.269
APM6	I am willing/interested in participating in green activities	5.80	6	7	1.384
PM1	Destruction of the ozone layer	6.18	7	7	1.200
PM2	Industrial water pollution	6.47	7	7	1.012
PM3	Industrial air pollution	6.38	7	7	1.028
PM4	The content of pesticides in food	6.26	7	7	1.095
PM5	Hazardous waste	6.40	7	7	1.094
PM6	Contamination of drinking water	6.49	7	7	0.988
PM7	Global warming	6.32	7	7	1.130

(Continued on following page)

TABLE 2 (*Continued*) Results of descriptive statistics.

Item	Item names	Mean	Median	Mode	Std. Deviation
PM8	Ocean pollution	6.45	7	7	1.009
PM9	Endangered species	6.21	7	7	1.170
PM10	Destruction of the tropical forest	6.40	7	7	1.047
CV1	I only buy green products	4.84	5	5	1.370
CV2	I spend time and effort on environmental activities such as recycling	5.06	5	5	1.368
CV3	I believe a person can do a lot to promote the environment	6.01	6	7	1.176
CV4	I am able to buy green products, but I don't have time and energy for environmental activities	5.09	5	5	1.539
CV5	I don't want to change my lifestyle to promote the environment	3.31	3	1	1.952
CV6	I may buy green products from time to time, but I am not involved in environmental activities	4.63	5	5	1.687
CV7	I don't buy green products	3.15	3	1	1.983
CV8	I believe that the organisations and the government should solve environmental issues	5.43	6	7	1.571
CV9	I am the least involved in green activities	3.85	4	5	1.889
CV10	I believe that there is not much that an individual can do in solving environmental issues	3.78	4	1	2.163
CV11	Government and organisations should promote the environment	5.95	7	7	1.394
APE1	I take into account the negative effects of production and consumption on the natural environment	5.36	6	6	1.437
APE2	I prefer green products to conventional products	5.38	6	6	1.356
APE3	I feel that green products are priced higher compared to conventional products	5.89	6	7	1.334
APE4	I believe that the price of the green product affects my purchasing behaviour	5.30	6	7	1.623
CPE1	I try to buy energy efficient products and appliances	5.64	6	7	1.310
CPE2	I avoid to buy products with excessive packaging	5.20	5	5	1.455
CPE3	When there is a choice, I choose the product which causes the least pollution	5.41	6	6	1.368
CPE4	I changed products/brands for green reasons	5.00	5	5	1.550
CPE5	I make every effort to buy products made from recycled paper	5.21	5	5	1.498
CPE6	I use green soaps and detergents	4.85	5	5	1.601

(Continued on following page)

TABLE 2 (*Continued*) **Results of descriptive statistics.**

Item	Item names	Mean	Median	Mode	Std. Deviation
CPE7	I convinced family members or friends not to buy some harmful products	4.96	5	6	1.633
CPE8	Whenever possible, I buy products packed in reusable containers	5.35	6	7	1.516
CPE9	I try to buy products which can be recycled	5.46	6	7	1.448
CPE10	I buy high efficiency light bulbs to save energy	5.78	6	7	1.402
IPM3	Organisations which produce/ promote green products are really concerned about the environment	5.49	6	6	1.326
IPM4	Consumers have become much more concerned about environmental protection in recent years	5.26	5	6	1.388
SCV1	I am happy with my decision to buy green products	5.72	6	7	1.359
SCV2	I am happy to buy green products	5.80	6	7	1.256
SCV3	I believe I am doing the right thing in purchasing green products	5.72	6	7	1.336
SCV4	I feel that I can contribute to environmental protection and sustainable development	5.85	6	7	1.250
SCV5	All in all, I'm happy to buy a product if it's eco-friendly	5.92	6	7	1.231
SCV6	I am generally happy with green products because of my concern for the environment	5.74	6	7	1.297

Note: Criterion for the mean of respondents' answers: 1) 1<a<1.85, Totally disagree; 2) 1.86<a<2.71, Generally disagree; 3) 2.72<a<3.57, Partly disagree; 4) 3.58<a<4.43, I do not agree or disagree; 5) 4.44<a<5.29, Partly agree; 6) 5.3<a<6.15, Generally agree; 7) 6.16<a<7,01, Totally agree.

2.5 Behavior of generation Z consumers in purchasing a green product

Social behavior indicates for the representatives of Generation Z different behaviors and preferences regarding consumption and the manner of making purchasing decisions (Puiu, 2016). Although people are aware of the need to protect the environment, including through the behavior adopted when purchasing green products, sometimes a lack of responsible behaviour is manifested through specific actions (Hicks and Hicks, 2003). Even if Generation Z has a green consciousness, in certain periods they lack motivation, which prevents the millennials from putting into practice the spirit required (Gómez-Román et al., 2020). The purchasing behavior of a green product is also reflected in the way in which people feel correctly and completely informed about everything that the purchasing process entails. Ever since the last century, the need of efficiency by simplifying information activities has been reiterated (Herberger, 1975), and it is currently practiced with very good results in terms of the sale volume of green products. Thus, any purchasing behavior of a green product will be modified for the benefit of society (Gierszewska and Seretny, 2019). The green purchasing behavior of Generation Z representatives will increase when individuals operate personally and professionally in a predominantly green environment. Thus, we can see that the purchase of green products is increasingly frequent and sometimes a little encouraged by the development of technology (Jaciow and Wolny, 2021).

In correlation with the principle of quality management and customer orientation, respectively, the companies producing or supplying green products and services supported directly or through outsourcing the research to identify as faithfully as possible the profile of the consumer, including their gender. Thus, the results of the study conducted by Davies et al. (1995) in the period 1989–1993 with actual buyers of green products as subjects highlighted that in that period, in relation to the size of purchases of such products and the degree of loyalty, the actual buyers were represented by women in the 30–45 age category, with children, and above average financial resources. Irianto (2015) and Bojkovska et al. (2017) demonstrated the tendency of women to purchase green products, their orientation towards protecting the environment and their own health as well as that of their family, while Hojnik et al. (2019) did not capture gender differences. The previously mentioned

TABLE 3 Results of Cronbach's Alpha test.

Constructor	Cronbach's Alpha	Interpretation
Green Marketing practices	0.954	Excellent internal consistency
Environmental protection attitude	0.919	Excellent internal consistency
Environmental issues	0.959	Excellent internal consistency
Green consumer identification	0.808	Good internal consistency[a]
Green product purchase	0.793	Good internal consistency[b]
Sustainable consumer behaviour	0.934	Excellent internal consistency
Environmental protection	0.722	Good internal consistency
Green consumer satisfaction	0.958	Excellent internal consistency

[a]Note: Value of Cronbach's Alpha coefficient when item 3 is supressed.
[b]Value of Cronbach's Alpha coefficient when item 4 is supressed.

research works show us a predominant similarity of behavior in female consumers with regard to consumers both representatives of Generation Z and those of previous generations, and the higher degree of receptivity to purchase green products, compared to male consumers.

Thus, it was found that there were attempts to define the profile of the consumers of green products according to their purchasing behavior, materialized in price acceptance, loyalty to the brand, or curiosity towards new products (Shrum et al., 1995). The purchasing and consumption decision among Generation Z representatives for green products is analyzed from several perspectives (economic, legal, ethical) (Pelikánová and Hála, 2021). Generation Z keeps more informed than other generations, choosing mainly the mass media as a source of information (Choi et al., 2021). Although the previously mentioned research works and those conducted by other authors (Shwetha, 2019) reflect an interest of Generation Z towards purchasing green products, concern for renewable energy, sustainability initiatives, this phenomenon cannot be extrapolated on a large scale to Generation Z to a high extent, as we are currently also facing negative phenomena regarding the purchasing and consumption behavior of young people, reflected in the massive food waste, and the lack of a green behavior (Kymäläinen et al., 2021). A research work conducted at the end of 2020 on the youngest representatives of Generation Z illustrates that, relative to gender, young men know more details and have more information and knowledge about green products and concepts, obtained in a proportion of over 50% from the Internet and social media (Guzel, 2020). In this sense, it is important that producers and traders stimulate through specific ways of promotion the responsible behavior of young people, regardless of gender, of positive perceptions towards green products and sustainability (Mohd Suki, 2013).

When purchasing green products, consumers mainly request information about the nutritional value and the content of chemical residues, and the concern for one's own health, the environment or the growth of the economy leads to the purchase of such products (Tsakiridou et al., 2008).

The analyses performed so far in an attempt to identify the particularities in the purchasing process specific to Generation Z have divided opinions in this field. Thus, we can consider that the phenomenon of purchasing green products is mainly a generational characteristic (Eastman and Liu., 2012) or, on the contrary, it is less relevant than the research of preferences, implicitly segmenting consumers according to gender, income and education (Meredith and Schewe, 2003). It is also necessary to study Generation Z and its representatives, respectively, as carefully as possible in order to approach effective marketing strategies. It is necessary to identify the purchasing behavior of green products for this generation in order to be able to discover the motivations determining these behaviors (Young and Hinesly, 2012; Parment, 2013).

According to this dimension resulted from the literature, the research hypothesis tested in our study is the following:

Hypothesis 5 (H5): There is a direct and significant relationship between the willingness to purchase a green product and the sustainable behavior of Generation Z consumers.

2.6 Role of sustainable behavior in environmental protection and the satisfaction of the generation Z consumer

2.6.1 Sustainable behavior of generation Z consumer

The severity of environmental problems, as well as global awareness of the balance between economic development and environmental conservation led consumers to adopt sustainable lifestyles and accept sustainable consumption patterns (Su et al., 2019). Thus, changing consumer lifestyles, environmental pollution and the determination to improve the quality of life have become prerequisites for new generations to take environmental criteria into account when making choices or making decisions. In this sense, the representatives of Generation Z present different behavior models, being interested not only in the present, but also in the future impact of their actions, they show a greater interest in actively participating in social issues, as well as an increased responsibility (Song et al., 2020).

Generation Z consumers are known as the most socially aware and responsible, with responsible consumption, self-care and environmental care (Barber et al., 2009), they are highly motivated (Calk and Patrick, 2017), predominantly engaged in a specific consumer culture due to technological progress and innovations. There are stereotypes indicating the existence of prejudices according to which female consumers are predominant in the panel of purchasers of green products, due to the fact that this type of purchase is associated more with a female attribute (Brough et al., 2016).

TABLE 4 Constructor reliability.

Constructor	Loading factor
Green Marketing practices CR = 0.955	
PGMk1	0.877
PGMk2	0.896
PGMk3	0.858
PGMk4	0.813
PGMk5	0.767
PGMk6	0.835
PGMk7	0.883
PGMk8	0.892
Environmental protection attitude CR = 0.921	
APM1	0.833
APM2	0.844
APM3	0.763
APM4	0.831
APM5	0.844
APM6	0.754
Environmental issues CR = 0.960	
PM1	0.748
PM2	0.868
PM3	0.880
PM4	0.796
PM5	0.867
PM6	0.888
PM7	0.813
PM8	0.905
PM9	0.779
PM10	0.855
Green consumer identification CR = 0.789	
CV1	0.324
CV2	0.177
CV3	0.497
CV4	0.770
CV5	0.654
CV6	0.740
CV7	0.366
CV8	0.728
CV9	0.654
CV10	0.175
Green product purchase CR = 0.803	
APE1	0.822
APE2	0.877
APE3	0.555
Sustainable consumer behaviour CR = 0.921	
CPE1	0.679
CPE2	0.657
CPE3	0.805
CPE4	0.704
CPE5	0.825
CPE6	0.695
CPE7	0.734
CPE8	0.777
CPE9	0.801
CPE10	0.656
Environmental protection CR = 0.716	
IPM3	0.767
IPM4	0.726
Green consumer satisfaction CR = 0.954	
SCV1	0.872
SCV2	0.911
SCV3	0.865
SCV4	0.863
SCV5	0.882
SCV6	0.889

(Continued in next column)

TABLE 4 (*Continued*) Constructor reliability.

Note: CR: composite reliability.

Contrary to the results of previous studies, the research conducted by Parzonko et al. (2021) showed that Generation Z representatives in Poland are less involved in pro-environmental behaviors than people from previous generations. In general, their sustainable behavior is based mainly on economic factors which bring financial benefits and is reflected in actions such as choosing public transport as a basic means of transport, turning off the lights when leaving a room or those imposed by legal regulations.

According to this dimension resulted from the literature, the research hypothesis tested in our study is the following:

Hypothesis 6 (H6): The sustainable behavior of Generation Z consumers has a positive and significant influence on environmental protection.

2.6.2 Environmental protection and green consumer satisfaction

The effective management of the environmental protection activity is a long, expensive phenomenon, not at all easy to implement, which involves all categories of the resources of an organization, but with very positive results, benefits and perspectives for the environment (Ştefănică and Butnaru, 2019). Purchasing behavior, responsible consumerism practices and environmental protection attitude of Generation Z consumers were the subject of interest in the research conducted by Walters (2021), Võ (2019) and Gajda (2020). Many of the recent research works in the field gather representatives of Generations Y and Z in the sample, in order to identify purchasing attitudes regarding green products, awareness of environmental issues, information held about the concepts of GMk and GMkP, elements which indicate that there are many similarities of behavior regarding the representatives of the two generations, who want to be informed how to ensure the consumption of healthy products in the family so as to meet the requirements of environmental protection (Chandra, 2019).

It is certain that we can identify behaviors illustrating young people's positive perception of the importance of environmental protection through activities such as recycling, selective collection and purchase of energy efficient equipment (Hansmann et al., 2006; Aizawa et al., 2008). Considering these aspects, Anders (2021) believes that Generation Z is the one who will dictate many of the future directions and strategies of companies, including the trends in the labor market. Therefore, green marketing practices influence the behavior of Generation Z consumers regarding the adoption of

TABLE 5 Convergent validity.

Constructor	AVE
PGMk - Green Marketing practices	0.729
APM - Environmental protection attitude	0.660
PM - Environmental issues	0.710
CV - Green consumer identification	0.307
APE - Green product purchase	0.584
CPE - Sustainable consumer behaviour	0.541
IPM - Environmental protection	0.558
SCV - Green consumer satisfaction	0.775

Note: AVE: average variance extracted.

environmental protection activities, given the role of the constant transmission of practices and the highly effective targeted manner, on all channels and through all the means to which Generation Z exponents have access.

Similarly, the authors Dabija et al. (2020) state that members of Generation Z express a very strong interest in sustainable development and social responsibility and tend to get involved in environmental protection activities, because they bring them great satisfaction (Ștefănică and Sandu, 2019). The conclusions of Witek and Kuźniar (2020) place the female population in a superior position in terms of receptivity to green consumer quality, being prone to pay a higher price and having an important concern for environmental protection.

According to this dimension resulted from the literature, the research hypothesis tested in our study is the following:

Hypothesis 7 (H7): The sustainable behavior of Generation Z consumers has a positive and significant influence on their satisfaction.

Figure 1 shows the theoretical model regarding the relationship between the sustainable behavior of the consumer based on the determining factors influencing this behavior with an impact both on the environmental protection and on the green consumer satisfaction.

The theoretical model proposed is based on the research conducted by Bhatia and Jain (2014), Shiel et al. (2020) and Gelderman et al. (2021) regarding green marketing practices, consumer's perception and preferences for environmental friendly products, also sustainable development and responsible consumption behavior. Starting from these studies, our article proposes testing 7 research hypotheses, formulated on the basis of the 8 dimensions and 57 research items validated in the studies conducted by Bhatia and Jain (2014), Shiel et al. (2020) and Gelderman et al. (2021).

3 Methodology

This research is designed as a quantitative study aiming to investigate the relationship between the determining factors and environmentally responsible behavior of Generation Z consumers, as well as the relationship between the sustainable behavior of the members of this particular group and environmental protection and green consumer satisfaction. The first approach is to estimate a model to test the relationships between GMk practices, environmental protection attitude, environmental issues, identification with the green consumer, and the purchase of green products and the sustainable behavior of Generation Z consumers. The second approach involves testing the relationships between the sustainable behavior of Generation Z consumers and the environmental protection, and the degree of satisfaction of the green consumer, respectively.

In this analysis, we used structural equation modelling using the least squares method (PLS-SEM) (using IBM SPSS AMOS 23), to test the statistical hypotheses formulated, also to estimate the relationships between endogenous and exogenous variables.

The quantitative approach was performed by investigation, using a questionnaire with 33 questions as a data collection tool, resulting in 784 completed questionnaires with valid answers. The questionnaire was developed according to the dimensions validated by the studies conducted by Bhatia and Jain (2014), Shiel et al. (2020) and Gelderman et al. (2021). In addition, our research tool includes 6 dimensions (green marketing practices–PGMk 1-8, environmental protection attitude–APM 1-6, environmental issues–PM 1–10, green consumer identification–CV 1–11, green product purchase–APE 1-4, environmental protection–IPM 3–4) which were validated by Bhatia and Jain (2014), one dimension (sustainable consumer behavior–CPE 1–10) validated by Shiel et al. (2020) and one dimension (green consumer satisfaction–SCV 1–6) validated by Gelderman et al. (2021). Therefore, there are 8 dimensions and 57 validated items. The respondents are students from university centers in Romania, aged between 18 and 29, coming from an urban environment. We chose to study the perception of young people of Generation Z primarily because it has been studied relatively little so far, and because more and more young people are concerned about environmental protection (Võ, 2019; Gajda, 2020; Walters, 2021). In addition, the young people of Generation Z are very interested in sustainable development and social responsibility (Dabija et al., 2020), responsible consumption (Barber et al., 2009), they are motivated in their decision to adopt measures to protect the environment (Calk and Patrick, 2017), which largely depends on their satisfaction as green consumers (Witek and Kuźniar, 2020).

Thus, the target group received a link to an online survey made in Google Forms to answer the questions in the questionnaire. The questionnaires were anonymous to ensure the confidentiality and reliability of the data. The measurement scale of the items included a 7-point Likert-type construction, from “totally disagree” to “totally agree”.

4 Results

4.1 The descriptive statistical analysis report

Table 1 shows the respondents' characteristics. Analyzing it, we can see that the majority of respondents who answered the questionnaire are female (71.56%). Most of the respondents come from the urban environment, regardless of their gender. Analyzing the statistical data by age groups, we can see that the respondents who answered the questionnaire are people from Generation Z (age group 18–29 years old), their proportion being 100.00%. Students' personal incomes, as shown in the table, are mostly under 1000 lei, the equivalent of 200 Euros, i.e., in a proportion of 39.54%.Unlike the

TABLE 6 Fornell-Larcker criterion analysis for checking discriminant validity.

	PGMk	APM	PM	CV	APE	CPE	IPM	SCV
PGMk	0.853	0.688	0.631	0.123	0.609	0.460	0.575	0.518
APM	0.688	0.812	0.521	0.096	0.631	0.567	0.644	0.608
PM	0.631	0.521	0.840	-0.036	0.410	0.320	0.414	0.398
CV	0.123	0.096	-0.036	0.509	0.264	0.209	0.276	0.043
APE	0.609	0.631	0.410	0.264	0.751	0.747	0.510	0.685
CPE	0.460	0.567	0.320	0.209	0.747	0.733	0.419	0.747
IPM	0.575	0.644	0.414	0.276	0.510	0.419	0.747	0.440
SCV	0.518	0.608	0.398	0.043	0.685	0.747	0.440	0.880

personal income, the family income is mostly between 2000 and 4000 lei (between 400–800 Euro).

The results of descriptive statistics are showed in table 2 and they present the mean, median, module and standard deviation of each indicator separately. The mean value of 6.28 shows that the respondents totally agree with the importance of green marketing practices of organizations with a role in the acquisition by the consumer of a sustainable behavior with benefits in environmental protection. Regarding the respondents' attitude towards environmental protection, they generally agree with the items in the questions (the mean is 5.82). Regarding environmental issues, the people who answered the questionnaire totally agree with the items formulated (the mean is 6.30). The mean value of 4.65 shows that the respondents mostly agree with the statements regarding the identification of the green consumer profile. Regarding the way of purchasing a green product, the mean was 5.48, which means that the people who answered the questionnaire generally agree with the items formulated. The respondents also generally agree with the answers given in the case of environmental protection activities (with a mean of 5.38), also with those regarding consumer satisfaction when consuming green products (the mean is 5.79). The mean of 5.29 shows that the respondents partially agree with the statements regarding the sustainable consumer behavior. The calculation of means for each constructor was done taking into account the values of the data representation scale, which has values between 1 and 7.

4.2 External models

Within this study, we defined 8 constructors, each of them including at least 3 measurement items. The participants were asked to rate each item on a 7-point Likert scale (1-totally disagree and 7-totally agree). We examined the relationship between each constructor and the items using measurement model analysis, consisting of reliability and validity tests. On this basis, we calculated reliability of the items and constructors, and convergent and discriminant validity for the constructor.

Constructor reliability allows the evaluation of the consistency of a variable or set of variables in its intended measurement (Straub and Gefen, 2004). Composite reliability and the Cronbach's Alpha test are used to determine reliability. The data obtained for the Cronbach's Alpha test are presented in table 3. Analyzing these data, we can say that we are dealing with an excellent consistency, in other words there is a close connection among the items of each constructor.

Composite reliability, also identified as constructor reliability, is a measure of internal consistency within a scale of items, being similar to Cronbach's Alpha test. Its calculation was made using factor loadings. The values of this indicator must be above 0.7. The analysis of the factor loading data for each of the 8 constructors indicates that they are all reliable (the results are shown in Table 4).

To test the validity of the constructors, we used convergent validity and discriminant (divergent) validity. To determine convergent validity, we used the average of the extracted dispersion (Average Variance Extracted-AVE), as suggested in the work of Fornell and Larcker (1981). Its value must be above 0.5 to show that the error value measured is not above the constructor dispersion. The values found for the 8constructors are presented in table 5.

TABLE 7 Summary of the structural model analysis

			Estimate	S.E.	C.R.	P	Is the hypothesis supported?
H1 Sustainable_behaviour	<--	Green_Practices	0.003	0.026	0.131	0.896	No
H2 Sustainable_behaviour	<--	Environmental_protection_attitude	0.239	0.026	9.232	***	Yes
H3 Sustainable_behaviour	<--	Environmental_issues	0.009	0.027	0.321	0.749	No
H4 Sustainable_behaviour	<--	Consumer_identification	0.091	0.059	1.534	0.125	No
H5 Sustainable_behaviour	<--	Green_product_purchase	0.468	0.031	15.097	***	Yes
H6 Environmental_protection	<--	Sustainable_behaviour	0.504	0.058	8.758	***	Yes
H7 Consumer_satisfaction	<--	Sustainable_behaviour	0.981	0.056	17.470	***	Yes

As we can see in table 5, all the constructors, except the constructor "green consumer identification", have values above 0.5. Given that the CR of the constructor is above 0.7 and only the AVE is below 0.5, we can say that the convergent validity of the constructor is adequate (Fornell and Larcker, 1981). Discriminant validity test was performed in this paper to see if one constructor has more variation in measurements than other constructors. To achieve this, we made a comparison between the square root of AVE and the correlation between the constructor and another constructor. The results in table 6 show that discriminant validity was met.

If this criterion is not met, then there is a problem with your questionnaire, thus, the items you claim are unrelated are in fact related.

4.3 Structural model analysis

To test the hypotheses formulated, we used structural model analysis. This model was used to test the relationships between GMk practices, environmental protection attitude, environmental issues, green consumer identification and green product purchase and the sustainable behavior of Generation Z consumers. In addition, we tested the relationships between the sustainable behavior of Generation Z consumers and the environmental protection, and the degree of satisfaction of the green consumer.

Table 7 shows the relationships between the variables and the significance of the relationship. Analyzing these results, we can see that there is no relationship between green marketing practices of organizations, environmental issues and green consumer identification and the sustainable behavior of Generation Z consumers (the β coefficient values are: β = 0.003, β = 0.009 and 0.091, respectively, for a significance threshold of 1%). As a result of these tests, hypotheses H1, H3 and H4 were not validated. Regarding the relationship with the sustainable behavior of Generation Z consumers, we can see that there is a positive relationship, both with the satisfaction it conveys to the consumer and with their environmental protection activities, so that hypotheses H2, H5, H6 and H7 were validated. The explained variation for the model verifies the relationship of sustainable behavior and is $R^2 = 0.517$, while for the relationship between behavior and satisfaction it is R2 = 0.537. The relationship between sustainable behavior and environmental protection activities has a coefficient of determination of $R^2 = 0.181$.

Table 8 in annex A shows the results of the structural model presented in Figure 2 and the relationships among the items.

5 Discussion

In this study we used structural analysis (SEM), which tested the following hypotheses:

Hypothesis 1 (H1): There is a direct and significant relationship between the GMkP of organizations and the sustainable behavior of Generation Z consumers.

With respect to this hypothesis, we found that there was no significant difference in responsible consumption behavior regarding the green marketing practices (β = 0.003, p = 0.896), which means that the null hypothesis is accepted and it can be inferred that green marketing practices do not affect sustainable consumer behavior. So H1 is not supported. This phenomenon is explained by the fact that GMkP is not known and implicitly adopted in their entirety (Bhavana and Thiruchanuru, 2018) even if young people have several objectives related to the social and ecological side (Kılıç et al., 2021). From this point of view, the members of Generation Z have grown up in an environment with a high level of awareness regarding the importance of environmental responsibility. As a result of school education, they learned the benefits of recycling, with a strict future approach, regarding GMk and GMkP (Líšková et al., 2016) concepts that are critical to be correctly understood by young people (Baran et al., 2016). Although the concepts of GMk and GMkP have been known since primary grades (Lerch, 2020), the conclusion of our study shows that GMkP does not affect sustainable consumer behavior. Some studies have shown correlations between GMkP and the behavior of Generation Z through actions that manage to connect with young people's preferences (Budac, 2014; Dabija et al., 2019; Adisa et al., 2021), as well as the lack of correlations, through the existence of higher expectations among consumers who have less pro-sustainability manifestations (Parzonko et al., 2021). Focusing organizations on creating, recreating, and delivering sustainable practices will help in a time horizon depending on the degree of knowledge of Gen Z consumer behavior, with results regarding the development of sustainable behavior.

Hypothesis 2 (H2): This hypothesis was tested using the structural model, and the results show that there is a statistically significant relationship, so that H2 is accepted, proving that there is a relationship between the attitude towards the environment and sustainable consumer behavior. Sustainable consumer behavior is a good reason for increasing responsibility among young people concerned about it. Thus, consumers have implemented GMk measures in their purchasing behavior and implicitly to protect the environment (Suki

TABLE 8 Regression Weights: (Group number 1 - Default model).

			Estimate	S.E.	C.R.	P
Sustainable_behaviour	<---	Green_Practices	0.003	0.026	0.131	0.896
Sustainable_behaviour	<---	Environmental_protection_attitude	0.239	0.026	9.232	***
Sustainable_behaviour	<---	Environmental_issues	0.009	0.027	0.321	0.749
Sustainable_behaviour	<---	Green_product_purchase	0.468	0.031	15.097	***
Sustainable_behaviour	<---	Consumer_identification	0.091	0.059	1.534	0.125
Environmental_protection	<---	Sustainable_behaviour	0.504	0.058	8.758	***
Consumer_satisfaction	<---	Sustainable_behaviour	0.981	0.056	17.470	***
Agreement3	<---	Environmental_protection	1.000			
Agreement4	<---	Environmental_protection	0.992	0.109	9.114	***
I34statements1	<---	Consumer_satisfaction	1.000			
I34statements2	<---	Consumer_satisfaction	0.962	0.026	37.541	***
I34statements3	<---	Consumer_satisfaction	0.976	0.029	33.669	***
I34statements4	<---	Consumer_satisfaction	0.910	0.027	33.462	***
I34afirmatii5	<---	Consumer_satisfaction	0.915	0.026	35.004	***
I34afirmatii6	<---	Consumer_satisfaction	0.971	0.027	35.565	***
I33agreement1	<---	Sustainable_behaviour	1.000			
I33agreement2	<---	Sustainable_behaviour	1.076	0.063	17.104	***
I33agreement3	<---	Sustainable_behaviour	1.216	0.059	20.583	***
I33agreement4	<---	Sustainable_behaviour	1.222	0.067	18.248	***
I33agreement5	<---	Sustainable_behaviour	1.359	0.065	21.022	***
I33agreement6	<---	Sustainable_behaviour	1.248	0.069	18.033	***
I33agreement7	<---	Sustainable_behaviour	1.337	0.071	18.949	***
I33agreement8	<---	Sustainable_behaviour	1.306	0.065	19.937	***
I33agreement9	<---	Sustainable_behaviour	1.280	0.062	20.486	***
I33agreement10	<---	Sustainable_behaviour	1.037	0.061	17.097	***
Practices1	<---	Green_Practices	1.000			
Practices2	<---	Green_Practices	0.971	0.026	36.740	***
Practices3	<---	Green_Practices	1.023	0.031	33.514	***
Practices4	<---	Green_Practices	1.009	0.033	30.253	***
Practices5	<---	Green_Practices	1.018	0.037	27.284	***
Practices6	<---	Green_Practices	1.019	0.032	31.829	***
Practices7	<---	Green_Practices	0.956	0.027	35.625	***
Practices8	<---	Green_Practices	1.041	0.029	36.444	***
CV1	<---	Environmental_protection_attitude	1.000			
CV2	<---	Environmental_protection_attitude	1.006	0.035	28.600	***
CV3	<---	Environmental_protection_attitude	0.996	0.040	24.636	***
CV4	<---	Environmental_protection_attitude	0.989	0.035	27.948	***
CV5	<---	Environmental_protection_attitude	1.012	0.035	28.609	***
CV6	<---	Environmental_protection_attitude	0.987	0.041	24.235	***

(Continued on following page)

TABLE 8 (*Continued*) Regression Weights: (Group number 1 - Default model).

			Estimate	S.E.	C.R.	P
PM1	<---	Environmental_issues	1.000			
PM2	<---	Environmental_issues	0.978	0.038	25.987	***
PM3	<---	Environmental_issues	1.007	0.038	26.392	***
PM4	<---	Environmental_issues	0.971	0.041	23.489	***
PM5	<---	Environmental_issues	1.056	0.041	25.929	***
PM6	<---	Environmental_issues	0.977	0.037	26.709	***
PM7	<---	Environmental_issues	1.024	0.043	24.063	***
PM8	<---	Environmental_issues	1.017	0.037	27.307	***
PM9	<---	Environmental_issues	1.015	0.044	22.897	***
PM10	<---	Environmental_issues	0.997	0.039	25.530	***
Green_consumer_quality1	<---	Consumer_identification	1.000			
Green_consumer_quality2	<---	Consumer_identification	0.546	0.133	4.111	***
Green_consumer_quality4	<---	Consumer_identification	1.727	0.228	7.571	***
Green_consumer_quality5	<---	Consumer_identification	3.392	0.401	8.457	***
Green_consumer_quality6	<---	Consumer_identification	2.490	0.304	8.187	***
Green_consumer_quality7	<---	Consumer_identification	3.311	0.394	8.398	***
Green_consumer_quality8	<---	Consumer_identification	1.299	0.195	6.664	***
Green_consumer_quality9	<---	Consumer_identification	3.101	0.370	8.372	***
Green_consumer_quality10	<---	Consumer_identification	3.193	0.390	8.188	***
Purchase1	<---	Green_product_purchase	1.000			
Green_consumer_quality11	<---	Consumer_identification	0.551	0.135	4.081	***
Purchase2	<---	Green_product_purchase	1.006	0.043	23.484	***
Purchase3	<---	Green_product_purchase	0.626	0.041	15.381	***

and Suki, 2019) even though the study by Nguyen (2021) shows that there are representatives of Generation Z whom GMkP measures adopted by companies do not influence. Therefore the intention to purchase green products is rare, random, or non-existent. Our research results differ from these studies, as the findings suggest a relationship between the attitude towards the environment and green consumption behavior. Moreover, some studies emphasize the importance that protecting the environment and sustainable behavior has on the characteristics of Generation Z (Malikova, 2021), both through the awareness and application of purchase decisions and through the implementation of principles aimed at respect for the environment (Noor et al., 2017). Generation Z is aware of the importance of protecting the environment by acting in this direction with increasingly safe and efficient steps. Generation Z has particularities in consumer behavior in choosing green products, which leads manufacturers and retailers to consider the development, promotion, and sale of this particular category of products, namely green products (Dabija et al., 2020).

Hypothesis 3 (H3): There is a direct and significant relationship between the perception of environmental issues and the sustainable behavior of Generation Z consumers.

This hypothesis was tested using the structural model and the results show that there is not a statistically significant relationship between environmental issues and sustainable consumer behavior ($\beta = 0.009$, $p = 0.749$). The null hypothesis is accepted and can be inferred that the environmental issues do not affect the sustainable consumer behavior (H3 is not validated) even though environmental issues are a significant source of concern for many people around the world (Ştefănică et al., 2020). Moreover, the findings of our study refute to some extent the conclusions obtained by Chen et al. (2018) which show us that in Taiwan the degree of awareness of environmental issues has also increased for Generation Z consumers. Also, Hidayat and Hidayat (2021) showed that the majority of Generation Z youths show deep concern about the negative implications of a development that has consequences for environmental sustainability. However, from a theoretical point of view, the studies initiated still do not directly distinguish a correlation between environmental issues and the sustainable behavior of the analyzed generation (Arora and Manchanda, 2022; Djafarova and Foots, 2022), which determines the identification of some sustainable concerns that Generation Z has, and which can constitute the guarantee that

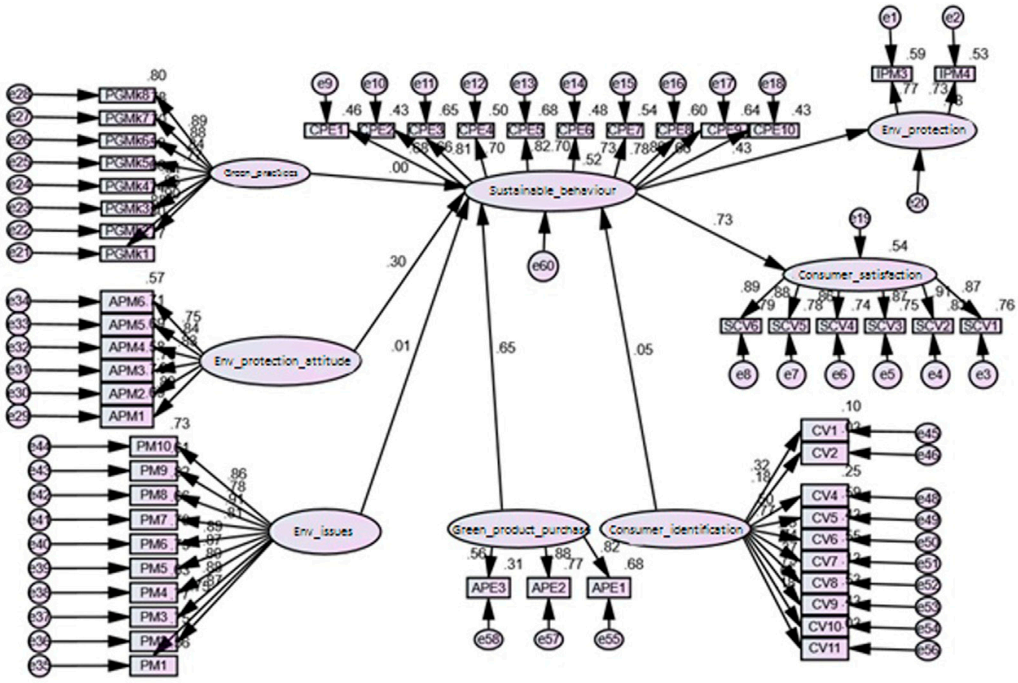

FIGURE 2
Structural model.

young consumers, through their behavior, will positively influence the quality of the environment.

Hypothesis 4 (H4): There is a direct and significant relationship between the degree of identification with the green consumer and the sustainable behavior of Generation Z consumers.

This hypothesis was tested using the SEM analysis and it is not validated. There is no relationship between green consumer identification and sustainable consumer behavior and it is supported by the value of the coefficient $\beta = 0.009$, with p-value $p = 0.749$). Therefore, H4 is not validated. The fact that there is no relationship between the identification of the ecological consumer and the sustainable behavior of the consumer, this aspect determines a behavior of individuals (Ştefănică et al., 2021) which is not always correlated with their perception of an ecological consumption behavior, the latter being negative, in discrepancy with personal perceptions regarding the concepts in their entirety (Deliana and Rum, 2019), which confirms the results obtained from our study. So, although the purchasing power of Generation Z exceeds that of Generation Y, it causes Generation Z to allocate a smaller budget for purchasing green products (Kowalska et al., 2021), which confirms that there is no relationship between identification of the ecological consumer and his sustainable behavior. Also, there are studies that address both the concept of the green consumer and that of sustainable behavior, without an automatic connection between the two being strongly highlighted (Casalegno et al., 2022; Casalegno et al., 2022). Although distinctly, Generation Z does not fully identify with a particular sphere of consumption, their decisions are filtered through attention to what constitutes sustainable behavior.

Hypothesis 5 (H5): There is a direct and significant relationship between the willingness to purchase a green product and the sustainable behavior of Generation Z consumers.

With respect to this hypothesis, we found that there was a significant difference in sustainable consumer behavior regarding the purchase of green products ($\beta = 0.468$, $p = 0.000$), which means that the null hypothesis is not accepted and it can be inferred that the purchase of green products does affect responsible consumption behavior. So H5 is supported. The conclusions of the present study are similar to those obtained by Gómez-Román et al. (2020) showing that although there is an ecological consciousness of Generation Z, in certain periods there is a lack of motivation, which prevents them from putting into practice the spirit necessary for the desire to buy an ecological product. In this sense, studies show us that any purchase behavior of an ecological product will be modified for the benefit of society (Gierszewska and Seretny, 2019), and the ecological purchase behavior of Generation Z representatives regarding the purchase of ecological products will be more frequent (Jaciow and Wolny, 2021). People who are typologically included in Generation Z cohorts manifest and materialize intentions to purchase ecological products, more pronounced than other generations and also in relation to the area of origin (Dąbrowski et al., 2022; Liang et al., 2022). Through the means that countries, organizations, promoters of sustainable consumption will have at their disposal and will use, they will be able to guide Generation Z towards the consumption of ecological products, responsibly and sustainably.

Hypothesis 6 (H6): The sustainable behavior of Generation Z consumers has a positive and significant influence on environmental protection.

Results show a positive correlation between sustainable consumer behavior and the environmental protection ($\beta = 0.504$, $p = 0.000$). Hypothesis H6 is also validated. The results of our study are not correlated with those obtained in the research conducted by Parzonko et al. (2021) who showed that representatives of Generation Z in Poland are less involved in pro-environmental behaviors than people from previous generations. This aspect is probably due to the fact that representatives of Generation Z show different behavior patterns, and show a greater interest in actively participating in social issues, as well as an increased responsibility towards the environment (Song et al., 2020). Sustainable behavior is included in the panel of possible and very important means of protecting the environment. This practice is also adopted among the representatives of Generation Z, who through their contribution make a major contribution to improving environmental conditions (Chaturvedi et al., 2020; Tran et al., 2022). The behavior of this generation can further guide the behavior of future generations towards the right approach to environmental habits and practices.

Hypothesis 7 (H7): The sustainable behavior of Generation Z consumers has a positive and significant influence on their satisfaction.

The results show that there is a positive correlation between sustainable consumer behavior and consumer satisfaction. Therefore, there is a positive effect, which is confirmed by the coefficient of the exogenous variable. So, the hypothesis H7 is validated. The positive correlation between sustainable consumer behavior and consumer satisfaction shows that we align with the results highlighted by the studies carried out by Ştefănică and Butnaru (2019), especially since, as Anders (2021) also shows us, Generation Z is the one that will dictate many of the guidelines and strategies future of the companies, including the trends that will manifest themselves on the labor market. A similar opinion is shared by Dabija et al. (2019) who support the fact that the young people of Generation Z express a very strong interest in sustainable development and social responsibility and tend to get involved in actions to protect the environment because they bring them great satisfaction (Ştefănică and Sandu, 2019). Generation Z is more inclined than other generations to purchase ecological products in terms of the satisfaction received (Suchanek and Szmelter-Jarosz, 2019; Cui et al., 2022). This generation is aware of the positive impact and the consistent size of their own and collective contribution to protecting the environment, elements that determine a specific satisfaction.

6 Theoretical contributions, practical implications and future implications

This study also brings theoretical contributions, constituting real support for the current and future practical side of all directly or indirectly stakeholders. Both academics and practitioners may use it as a starter for developing future research or designing market policies addressed to this consumer group, Generation Z. The following paragraphs develop these considerations and present in detail our research contribution and value for stakeholders.

6.1 Theotetical contributions

In this article, shaped as an extensive documentation and empirical research, we analyzed the elements which complete the profile of the green consumer, aspects related to the behavior of the consumer as a representative of Generation Z, as well as the GMk practices of the organizations in the context of their adaptation to the new requirements of the profile market. The results found confirmed the theories stated by Su et al. (2019), Krasulja et al. (2020), who mention the fact that the profile of the green consumer of Generation Z has different characteristics compared to other generations, because millennials are much more informed, they choose to purchase environmentally friendly products, they are more pragmatic, avoiding to waste food, and the main GMkP activities of the organizations sensitize them and shape their purchasing and consumption behavior of green products.

At the same time, although the young age sometimes prevents the young people of Generation Z from converting their opinions and intentions regarding the purchase of green products into actual purchases, due to financial limitations, their attitudes and knowledge can contribute to the formation of an appropriate behavior of purchasing green products and appreciation of GMkP activities of organizations, both for the current generation and for future generations.

Generation Z no longer ignorantly considers the green concepts, the characteristics of green products, environmental protection or the methods of preventing pollution through their own activities; this is the generation born in the middle of these transformations, and they assimilated and perceived them naturally. In this context, we can say that the young people of Generation Z are not only the human category who best feels the importance of GMK measures and practices, but can also be the best promoters of these concepts for the previous generations, who to a large extent become more arduously familiar with these elements. Generation Z is educated to desire healthy, green products, but they are trying to identify them at good prices, which is why organizations need to streamline both their production costs and promotion practices, without greatly affecting the final price.

Generation Z consumers show concern for the natural environment and this aspect is visible in their behavior and purchase reaction regarding products on the green market. In the consumption profile studied, the focus is oriented from quantity to quality. The practice of a sustainable behavior induces the consumers' feeling of satisfaction, caused by the awareness of the contribution both to environmental protection and to the practice of a healthy lifestyle, through a suitable diet, with green products.

Studies in the field highlight the preponderance of women as purchasers of green products, both for previous generations and for Generation Z. This results in a greater propensity to purchase green products on the part of the women, a fact that should not be confused with the degree of consumption of environmental friendly products related to people gender. It is well-known that in most cases the representatives of the female gender carry out the supply process for the family/group/union (Chen and Chai, 2010), an element which confirms the presumption of fair consumption of green products distributed by gender. The attempt to define an absolute green purchasing profile and consumption for Generation Z is still being observed and analyzed, because the reactions, personal implications, affinities, perceptions are not stabilized in order to be able to build a standard profile, but what is clearly reflected until now confirms the fact that we are talking about a more mature, conscious, economical generation, with an emphasis on the principles of a healthy life, in agreement with the norms of environmental protection. The first years of professional activity for Generation Z largely coincided with the onset of the COVID-19 pandemic, which influenced certain components of their natural behavior, given the state of uncertainty experienced, with multiple emotional connotations (Butnaru et al., 2021). The coming years will be able to stabilize the behavior, perception and profile of the Generation Z consumer of green products, including the exact determination of the impact of green marketing practices. The premises are promising, the behavior of Generation Z is currently sustainable, with an emphasis on environmental values and healthy consumption. This study aimed to identify the pattern of behavior and consumption of the young people of Generation Z at present, both in terms of the impact on environmental protection and the satisfaction given by the consumption of green products and the correlation of this pattern with the GMk practices of the organizations.

Our article contributes to strengthening the relationship between actual GMk practices targeting Generation Z and research by identifying particular consumption factors. Based on this perspective, the research validates the hypotheses through structural model analysis, while also providing from a theoretical perspective the image reflected in the research of the existing approaches, which must be constantly updated and adapted, in accordance with the ever-changing challenges and trends.

We believe that the main research limits are determined by the dynamism of the phenomenon illustrated over time, as well as the flexibility of consumption trends, which means adaptation to changes both by researchers and especially by producers. These limits require a close and uninterrupted collaboration between research and production, with the aim of adapting to the consumption profile of Generation Z. Through further analysis and research, we can contribute to shaping a realistic and current profile, which will come to the aid of researchers and companies, even of consumers of green products in the process of self-knowledge of the determining factors of consumption.

6.2 Practical implications

The results of this research, carried out following an extensive and refined collaborative documentation process, can be successfully integrated into the future strategic and operational activity of the main stakeholders that include or follow distinctly in establishing the profile of the target consumer Generation Z: businesses, managers, the academic environment, including consumers. From the managerial perspective, the research presents practical implications because it illustrates how Generation Z relates to environmental issues, the influencing factors in substantiating the purchase or consumption decision, concerns for ecological consumption, and environmental protection. Moreover, it is essential as it partly presents the influence of GMk practices of the companies on the behavior and the desire to involve or support sustainable consumption. These aspects can be taken into account in substantiating operating decisions. Thus, at the managerial level, companies worldwide should adopt ecological strategies and actively implement green marketing practices to promote as best as possible among consumers. On the one hand, it is necessary to know their customers as well as possible, the particularities of their consumption behavior, and the principles and rationales underlying the adoption of sustainable behavior. On the other hand, it is necessary to build a green production system valid for the entire product cycle, continue developing green products and processes, and have green supply chains that integrate as many ecological practices as possible. The field researched is not a static one, it requires systematic updates to get the most current, relevant and easy-to-implement data within the management systems of the actors on the green product market.

It is necessary to start innovative, sustainable businesses that incorporate green marketing practices from the planning and design phase, so that a business model that can be replicated and promoted, as a reference for those who want to transform their businesses into green, sustainable ones, and this study can provide some relevant elements of support. At the same time, in supporting such businesses, governments also have an essential role, encouraging this kind of initiative by offering financial and fiscal assistance to promote ecological practices or by implementing a system to protect intellectual property and improving the continuous improvement of environmental standards.

6.3 Future implications

This study aimed to identify the pattern of behavior and consumption of the young people of Generation Z at present, both in terms of the impact on environmental protection and the satisfaction given by the consumption of green products and the correlation of this pattern with the GMk practices of the organizations.

The academic environment relates to this type of research from a double standpoint: to continue the research of the described phenomenon through the prism of the background substantiated by the authors and the possibility of deepening the topic, and at the same time, from the position of the party that manifests a direct interaction with the representatives of Generation Z, through the possibility of knowing and understanding more effectively the actions of this generation and the foundation of future activity plans, specific to the needs of young people. From the consumers' perspective, the results suggest that responsible consumption, environmental actions, and awareness may have a significant impact at the individual level and on the environment. It can stimulate Generation Z consumers to perpetuate responsible behaviour and, at the same time, raise the awareness of other generations regarding the consumption of ecological products, leaning towards responsible consumption, paying more attention to GMkP campaigns, and involvement in environmental protection activities.

The validity of the results found in this extensive study offers the possibility both to the authors and to other researchers with study interests in this field to continue the analysis from an advanced stage. The future directions allow taking over the results obtained in this ample approach and improving their operationalization in order to build future models of management of GMkP, with impact in modelling the purchasing behavior of the new Generation Z.

We are encouraged, following the analyses performed, to deepen the research through further research, not necessarily due to reasons determined by principles or lacunar previous research, but for the permanent needs required by this field of orientation of generational green marketing practices of companies.

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.

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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The impact of environmental disclosure and the quality of financial disclosure and IT adoption on firm performance: Does corporate governance ensure sustainability?

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Introduction: The study's motivation is to investigate the role of environmental and financial disclosure, IT adoption, and good governance on firms' sustainability from 1990–2019. A sample of 75 financial institutions enlisted in Bangladesh's capital market was considered for relevant data collection.

Methodology: Secondary data sources were used for data accumulation, including annual reports of target FIs, economic review reports, and central banks publication. Several econometrical techniques have been implemented to document the empirical nexus and the elasticities of explained variables on firm performance.

Findings: In terms of baseline assessment, the study revealed a positive and statistically significant association between a firm's sustainability and target explanatory variables. Furthermore, the study extended the empirical valuation by implementing a system-GMM and documented a positive linkage between financial and environmental disclosure, IT adaptation, good governance, and the firm's performance sustainability.

Discussion: These study findings suggest that information symmetry, investor protection, and access to financial services foster and stabilize the firms' performance. Concerning corporate governance's mediating effect, the study established a mediating role with positive influences on financial performance augmentation. On the policy ground, the study postulated that financial policymakers should address fairness and integrity in disclosing information to the public. Enforcement has to be initiated to ensure good governance.

KEYWORDS

financial disclosure, environmental disclosure, IT adoption, corporate governance, financial performance

1 Background of the study

One of the primary issues that harm the principal–agent interaction is the asymmetry of information, which has been cited as one of the most significant contributors to aggravating the conflict of interest. Regarding firms' operational concerns and performance stability, lesser disturbance will prompt a better ambiance for growth; it is generally accepted that they have a good understanding of the business. The principals or owners of the company depend on the information that has been revealed to know how well the company is operating, particularly how well it is meeting its main purpose, which is maximizing wealth (Shanthi et al., 2015). It is not enough for information to be correct; it must also be current for it to be of any use to the person making a choice (Mugo, 2009; Andriamahery & Qamruzzaman, 2022a). Therefore, disclosure may be seen as the supply of timely and pertinent information to ensure complete transparency and an accurate image of the activities taken by the corporation in areas such as governance and financial performance.

In recent literature, a growing amount of research and discussion has been devoted to determining whether or not there is a connection between the responsible and socially sustainable conduct of businesses and their financial performance in the long run (Lassala et al., 2017; Ganlin et al., 2021; Alam, 2022). Due to the extensive globalization that markets have undergone and the growing demand of stakeholders for social commitment and transparency from businesses, social, environmental, and economic actions with sustainability criteria have been implemented (Adams, 2002; Moneva & Eduardo, 2008). Firms' performance may be influenced by general corporate practices and disclose pertinent information, which will be generated from a company's practice of social and economic integration. Additionally, the modern business environment is both dynamic and complicated. Shareholders have been put in danger of having their profits manipulated due to a lack of complete information on the firm's operations, as has been seen in recent years with an increase in the number of scandals, frauds, suspensions, and even delisting. As a consequence of high-profile business failures in recent years, the topic of corporate governance has started to assume an ever-increasing prominent role in the public arena, and it is anticipated that the trend for corporate governance practices will be ingrained extensively. The focus has shifted from the traditional "shareholders only" approach to corporate governance to a broader corporate governance model that identifies the issues and priorities of stakeholders. Poor corporate governance can negatively impact economies and the stability of financial systems and also have tangible, serious social and environmental consequences (Dusuki & Bouheraoua, 2011; Alam et al., 2022).

The study considered environmental disclosure, the quality of financial disclosure, IT adoption, and good governance in a firm's performance equation. After the financial crises in 2002 and 2008, companies worldwide became more conscious of providing more information to investors and consumers, particularly dealing with financial information. The literature has suggested that financial disclosure has demonstrated transparency and symmetry in information management, which prompts companies' superior performance with the firm's value proposition (Musleh Alsartawi, 2018). Over the last several decades, people's awareness of environmental concerns has dramatically expanded, and they prefer to see firms' contribution to restoring environmental balance (Ham et al., 2016). In 2015, the United Nations issued a resolution entitled "Sustainability Development Goals" (SDGs) as a response to several environmental challenges; since then, environmental concerns have emerged as major concerns for businesses, organizations in the public sector, and the worldwide community. The public now exerts greater pressure on businesses to be accountable for their environmental impact than in the past (Burgwal & Vieira, 2014). Therefore, for businesses to get legitimacy from the many stakeholders, they be transparent about their environmental responsibilities. It is not acceptable to let the presence of commercial enterprises affect the quality of the natural environment in the surrounding area. Due to the continual demand from stakeholders, businesses must formulate and implant environmental protection strategies, disclose environmental information, and actively involve environmental quality improvement. Environmental protection requirements arose due to the firms' operational sustainability (Albertini, 2014). Making information about the environment public was pioneered in various media types, such as annual and sustainability reports. Furthermore, the quality of environmental disclosure is affected by firm size, leverage position, and corporate governance (Akrout & Othman, 2016; Handoyo, 2018).

The significance of good corporate governance (CG, hereafter) in determining how well a company carries out its responsibilities and makes the most of its assets is generally recognized in every area of the world (Crifo et al., 2019) along with tracking how well the company performs (Dony et al., 2019). The successful completion of the business's goals and an increase in its performance's effectiveness may be aided by corporate governance, which provides helpful information to the organization. CG is a procedure that may be described as supervising and managing businesses using several legal and other criteria. GG contains a collection of concepts and methods that deal with the interaction between management and stakeholders by providing corporate services such as transparency in a business transaction, legal compliance, protection of shareholders' interests, and the organization's ethical ideals. There are a lot of different methods that are used to assess corporate governance in each company. A few of these mechanisms include the size of the board of directors, the make-up of the board, the audit committee, and the standing of the CEO (Al-Homaidi et al., 2019).

The current study used Bangladesh as a case study to examine the relationship between explanatory and explained variables. The following factors have guided the selection of the sample economy: first, a firm's actual information disclosure significantly affects performance, especially on a mark-based assessment. It suggests that the stock price behavior is due to investors' attitudes toward the firm based on publicly available information. Second, disclosing operational modernization and access to customers' services have a critical effect on a firm's sustainability, indicating the customer's confidence and preference for getting and availing the services, which are significantly guided by technological assistance. Additionally, financial institutions have increased their investment for IT inclusion in their processes to offer better services and retain their position in the market, especially in the last 20 years. Thus, this study examines the potential role of IT adaptation and diffusion effects on performance standards. Third, the sustainable growth of financial sectors is critically important for sustainable development but should come at the additional cost of environmental degradation. Thus, in recent times, environmental disclosure has become an alternative way to assess the firm's contribution to the economy, potentially affecting overall firm performance.

The novelty of the study lies in the following aspects: first, considering the existing literature, many studies have been initiated focusing on financial institutions' performance in different economies; however, the empirical assessment dealing with the financial institutions' performance in Bangladesh has yet to be extensively investigated. The present study has initiated the empirical assessment to establish a bridge in the existing literature with fresh insight. Second, on the comprehensive assessment, the study implemented an empirical model with aggregated aspects and industry-focused investigation. The motivation to execute the empirical model with industry-specific assessment is to get a comparative picture. Third, the study extended the empirical assessment with the incorporation of interactive terms dealing with the assessment of the mediating role of corporate governance on the financial performance of financial institutions in Bangladesh.

2 Theoretical assessment

According to the stakeholder theory, the primary objective of a company should be to advance the interests of its many stakeholders. The perception that companies have a positive reputation and image is constructed by stakeholders who believe the company has high environmental disclosure standards. Stakeholders have the right to get information on activities that affect the environment to assist them in making decisions. Najihah et al. (2020) demonstrated that companies try to improve their image to gain stakeholders' legitimacy and approval. This leads to an increase in the amount of money invested in the company, which, in turn, leads to an increase in the stock return. As a result, it is anticipated that companies that have improved their environmental performance and efforts will have a greater stock return.

Disclosure of financial information is an unavoidable need for companies' prosperity since these establishments depend on providing truthful and up-to-date data to assist investors in making decisions and influencing new investors (Lipunga, 2014; Nuhiu et al., 2017; Murshed et al., 2022). When a company's performance is strong, according to the signaling hypothesis, it is more likely to release detailed information to the market than when it is hiding negative news. This is done to prevent the company's share price from being undervalued and operates on the presumption that managers want to indicate that they are efficient and working to maximize shareholders' wealth. Managers might use different channels to communicate these signals to investors (Musleh Al-Sartawi et al., 2016).

In 1932, Adolf Berle and Gardiner developed the first corporate governance theory, which is still at the apex of theoretical discussion. In their book, Modigliani and Miller (1958) presented their capital structure theory. In addition, they advanced the notion that if there were no corporation taxes, the value of a levered business (based on taxes) would be the same as the value of an unlevered firm if the two firms were identical. This theory is called the MM1 preposition hypothesis in certain circles. Furthermore, they also put up the MM2 offer, in which they made use of the concept of taxing corporations, a situation in which a highly indebted firm can obtain a tax shield (benefit).

According to the signaling concept, a good company would purposefully signal the market. Consequently, the market is said to be able to discriminate between excellent and weak businesses. An effective signal can be recognized and caught by the market to function properly. The company's quality is shown by CG, which, in turn, will provide a signal by providing the financial statements and the information on corporate governance that the company achieved in a certain amount of time. The signal that a trustworthy company provides is considered good news. However, the signal given by a corporation that cannot be trusted is considered bad news.

3 Literature review

3.1 Corporate governance and firm performance

Regulators, shareholders, investors, and society have been forced to realize the importance of effective corporate governance, the only remedy for economic calamities in the 19th century due to a string of financial scandals and the collapse of large business houses. This understanding led scholars worldwide to focus their efforts on establishing the nature of the link between corporate governance and company performance. Numerous individuals were motivated to identify the various techniques that companies may consider to develop an effective corporate governance system and determine the impact of this mechanism on a company's financial performance. The role of corporate governance in effective decision-making and organizational strategical success has been extensively assessed in the literature. Considering the nexus between corporate governance and a firm's performance, existing literature suggests three lines of thought. First, many researchers have postulated a positive, statistically significant association between CG and firms' performances (Mia et al., 2014; Dony et al., 2019; Susanti et al., 2019; Ahmed et al., 2020; Murshed et al., 2021). Existing literature records have advocated that good governance practices ensure the availability of quality information and transparency in the managerial decision-making process and allow employees access to management information, thus allowing performance enhancement in the long run (Crifo et al., 2019; Gangi et al., 2019). Corporate governance is a rapidly evolving subject area that has been forced into necessitating the restoration of investor confidence in capital markets. It refers to the rules, procedures, and processes that govern and manage an organization. The literature argues that good governance is critical for a company's success (Alix Valenti et al., 2011). Agrawal and Knoeber (1996) assert that firms with good corporate governance rules could acquire financial resources for investment at a reduced cost, resulting in increased company value, particularly since investors prefer to do business with companies that adhere to sound governance standards. Moreover, good governance practices act as incentives for potential investors and encourage future investment, which eventually supports performance sustainability (Han Widiatmika & Sri Darma, 2018). In a similar line of study that is the nexus between CG and firms' performance sustainability, Munir et al. (2019) investigated Pakistan. They documented that good CG is a critical attribute for operational sustainability through organizational transparency, accountability, independence, and fairness.

An empirical test was conducted by Beasley (1996) to investigate the impact of the number of independent directors on the board of members on the incidence of financial crimes. A study found that a significant reduction in the possibility of fraud in financial statements occurs whenever a large number of independent directors serve on the board of directors. According to Dalton et al. (1999), it is essential to have independent directors as opposed to executive directors. Furthermore, the study revealed that independent directors have more access than executive directors to the resources and information supplied by third parties. Greater corporate governance, on the whole, contributes to an improvement in financial performance by lowering the risk that investors are exposed to and, as a result, assists in the recruitment of more investors (Manigandan et al., 2022; Spanos, 2005). Businesses can make the most of the available resources and predict that they will also have exceptional financial performance because have good corporate governance systems.

The second line of evidence suggests an adverse association between CG and financial performance (Appiah et al., 2017; Benadetta Munyiva et al., 2020). Patel et al. (2018) investigated the link between corporate governance and a firm's performance and exposed that company performance decreases as directors' ownership increases. Study findings indicate a negative relationship, particularly due to non-executive directors' inability to perform efficiently, effectively, and independently in the existing local and cultural context.

H_1: Corporate governance is positively connected with firms' performance sustainability.

3.2 IT adaptation and firm's performance

In particular, information and communication technology (ICT) has brought about a fundamental shift in how banks generally work and provide customer service in the banking industry. To catch up with the pace of global development, improve the quality of customer service delivery, and lower the cost of transactions, banks have made significant investments in ICT and have widely adopted ICT networks to deliver a wide variety of value-added products and services. This has been carried out to deliver various value-added products and services, and the expansion of information and communications technology has significantly influenced the development of more adaptable and user-friendly financial services. It is a commonly held belief among business leaders, those who influence policy, and people who research that the significance of new technologies and breakthroughs for economic development and competitiveness is unquestionable. However, not every new technological development or innovative idea succeeds. In light of the vast number of technological possibilities and financial innovations, which businesses have the potential impact on growth? Knowing which types of innovative activities and technologies are most clearly associated with increased competitiveness and growth is desirable. Alternatively, the success of new technologies and creative activities more or less probable is even more, significant than having that understanding (Koellinger, 2008; Andriamahery & Qamruzzaman, 2022b) when discussing topics such as technology, innovation, and other associated ideas, not always the case that performance is a one-way path. Successful companies may have easier access to funding, making it simpler to finance a greater number of investments and innovations (Abel & Blanchard, 1983; Hubbard & Kashyap, 1992). In addition, investments in technology and innovation may benefit firms' absorptive capacity (Cohen & Levinthal, 1989; Muneeb et al., 2022) and the availability of complementary resources such as skilled labor (Bresnahan et al., 2002), and learning-by-doing effects may occur. In the case of Vietnam, Le and Pham (2022) explored the impact of ICT development and banking profitability from 2009 to 2020 with a sample of 39 bank-based financial institutions. Study findings documented that ICT investment was positively connected to a firm's profitability; moreover, the study postulated that ICT advancements improve the banks' performance as they transition from analog to digital systems. In the case of e-business, Koellinger (2008) established a skeptical attitude favoring technological innovation and IT integration in the business process.

The study revealed that firms that rely on innovations not made possible by the internet are less likely to see growth compared to companies that rely on innovations made possible by the internet. To sum up, the literature suggested that innovation is not always associated with improved profitability which was a discovery. The fact that the responses of firms engaged in cutthroat competition are heavily dependent on the connection between innovative ideas and financial success makes it far more difficult to create the relationship. One of the most basic obstacles an inventor must face is stopping other companies from replicating a creative procedure or product. No firm on the market, not even the one that was the first to introduce a new invention to its sector, will be able to outcompete its competitors if they all adopt the same procedure and begin manufacturing the same product. This is due to the fact that all firms will use the same process, including the first firm to market items based on the concept (Teece, 2006). In that case, the time for each company that contributed to the innovation to enjoy extra benefits from their investment in the innovation is reduced. The issue is sometimes referred to as the appropriate dilemma (Geroski, 1995; Li & Qamruzzaman, 2022; Zhuo & Qamruzzaman, 2022).

H_2: IT adaptation positively accelerates the firms' sustainability.

3.3 Environmental disclosure and firm's performance

The inconclusive, earlier empirical findings and the link between environmental performance and financial success have led to inconsistent outcomes owing to the three different schools of thought that have lately emerged (Horváthová, 2010). According to Palmer et al. (1995) and Walley and Whitehead (1994), the neoclassical school of economic thought believes that environmental legislation results in increased business expenses. On the other hand, the conventional neoclassical hypothesis maintains that an improvement in environmental performance would increase expenses. This perspective is founded on the idea that efforts to reduce pollution and enhance environmental quality have diminished marginal net benefits. Nevertheless, the third school of assumption contradicts the other two schools of thought by establishing a link between environmental success and financial performance that is formed like an inverted-U association (Lankoski, 2000; Wagner, 2001). The connection between these two schools of thought is referred to as a "traditionalist" relationship in the negative sense and a "revisionist" relationship in the positive sense. According to this point of view, there will be a positive association between environmental performance and financial success up to the level of environmental performance at which economic advantages will be at their highest level (Ayesha et al., 2022; Azam et al., 2022; Gregory, 2022).

A group of researchers has confirmed the adverse influence of environmental disclosure on a firm's performance; for instance, Klassen and McLaughlin (1996), Jones and Rubin (2001), and Stanwick and Stanwick (2000) explored whether there was a correlation between environmental disclosure and the financial success of 469 large firms listed on the Forbes 500 list in 1994. Study findings show that firms rated well in terms of their financial success had a higher number of instances of environmental policies and environmental pledges than businesses that were ranked badly in terms of their financial performance. In addition, companies with medium financial success had the highest frequencies of firm environmental policies and commitment. Meng et al. (2013) examined the relationship between economic performance and the ED for 792 Chinese enterprises in 2006, 784 Chinese businesses in 2007, and 792 Chinese businesses in 2008. The empirical data demonstrated that the relationship between ED and firm performance is multiplicative and that ownership is a crucial institutional characteristic that impacts ED in China, from voluntarism to regulation. Their studies also demonstrated that the evaluation of corporate ED is related to financial performance and must exercise prudence concerning ownership type, which may vary from voluntarism to regulation.

For Indonesian manufacturing firms, the study by Arafat et al. (2012) revealed that environmental quality has positively augmented the firm's performance. However, the impact of environmental disclosure on financial performance was statistically insignificant, while concurrently having a big impact on a company's financial success are factors such as its environmental performance and transparency. These findings make it abundantly clear that businesses in developing nations will become more concerned with environmental sustainability and long-term profitability as time goes on. As a component of the environmental information disclosure, the environmental financial and non-financial information is made public. The environmental expenditures, investments, and provisions were all put into monetary terms in the financial report that dealt with the environment (Andriamahery & Qamruzzaman, 2022a; Xia et al., 2022). The literature exposed the link between environmental information disclosure and business performance and discovered that a high degree of environmental information disclosure might be helpful to a company's financial success (Gjergji et al., 2021) (Neu et al., 1998; Prencipe, 2004; Cormier et al., 2011). It is realistic to predict that firms would incorporate environmental awareness into their operations to take advantage of the potential financial advantages. This would be as follows: as a consequence, adopting an environmental policy will affect the choices made by the management of the firms, eventually leading to an improvement in the companies' financial performance (Stanwick & Stanwick, 2000; Qamruzzaman & Wei, 2018).

H_3: Environmental disclosure expedites the firms' profitability.

3.4 Financial disclosure quality and firm's performance

It has been shown that elevating the level of financial transparency a company presents positively impacts the business's overall success and is advantageous to the organization as a whole. Performance may be defined in terms of the business's profit margin, rate, or return on assets; alternatively, it may be assessed in terms of a rise in the company's stock value (Andrimahery and Qamruzzaman, 2022b; Liang & Qamruzzaman, 2022; Ma & Qamruzzaman, 2022). Alternatively, this performance may be measured in terms of the increase in the company's overall value. In the great majority of situations, it has been proven in the accounting literature that earnings, timely disclosures, and disclosures in addition to annual reports have an important link with one another, that is, to have a correlation (Shi & Qamruzzaman, 2022; Xia et al., 2022).

In recent years, financial disclosure (FD hereafter) has emerged as one of the most important tools for communicating information to those in charge of making decisions. This viewpoint is gaining support among a growing number of companies in a variety of countries all around the world. The dramatic increase in the number of individuals using the internet and the volume of information that is made available to the general public has substantially impacted the operation of various economic and legal institutions throughout the globe (Aqel & Ahmad, 2014; Miao & Qamruzzaman, 2021; Yingjun et al., 2021). By disclosing symmetric information to shareholders and stakeholders, FD promotes transparency, which contributes to a reduction in the agency problem. This may be performed by demonstrating the management team's commitment to openness and accountability throughout the operation of the business. Businesses could boost the demand for their shares and, as a result, lead to improvement in their long-term profitability if they provided a greater quantity of financial information to the public. The nexus between financial disclosure and financial performance was positive and statistically significant (Al-Mohannadi & Syam, 2007; Jullobol & Sartmool, 2015; Musleh Alsartawi, 2018). However, investors' ability to accurately evaluate the true performance of the companies may be hampered as a result of the vast amounts of information that have been published.

To maintain a healthy corporate governance system, companies must comply with the requirement that they promptly provide understandable and comparable information. This material should focus on the challenges associated with finances, management, and organization ownership (Richardson & Welker, 2001; Dai et al., 2022; JinRu & Qamruzzaman, 2022). In addition, the adoption of FD is considered in the context of the economics of financial disclosure as a method of minimizing agency difficulties. This is carried out as a means of mitigating agency problems. It has been stated that the successful implementation of FD is dependent not only on the dominant form of corporate governance in the nation but also on the supporting infrastructures that exist within it (Musleh Alsartawi, 2018)

H_4: Financial Disclosure Quality expedites the firms' profitability.

4 Data, variables, and methodology

4.1 Definition of variables

The motivation of the study is to gauge the impact of financial disclosure, environmental disclosure (ED), good governance (GG), and IT adoption on firms' performance sustainability by taking the financial sectors in Bangladesh.

Several proxies have measured financial performance following the existing literature as an explained variable. The present study has considered two proxies extensively used in the literature in measuring the firms' financial performance. First, the market value added, also known as MVA, is the difference between the current market value of a company and the total amount of capital that has been contributed to the company by its shareholders and bondholders. MVA can be calculated as a reflection of the performance of management:

Market value added = market value of the company − capital investment.

Second, the return on equity (ROE) calculates the percentage of a company's net income that was distributed to shareholders compared to the total amount of equity held by shareholders. ROE is a metric that may determine how profitable a firm is since it shows how much profit a company earns with the shareholders' investment. The return on equity is expressed as a percentage and found by using the following formula:

Return on equity = net income/shareholder's equity.

Stock return (SR) is considered a proxy for measuring the firms' performance based on market fraction. The following formula is implemented to drive the stock return with the closing stock price.

SR= (closing stock price (t)/closing stock price 0) − 1.

The key explanatory variables of the study are as follows: first, IT adoption: We measure IT adoption as a dummy, taking the value of 1(0) if the bank is above (below) the median of the ratio of tech and communication expenses to total operating expenses for 2020, and these firms are henceforth denoted "high (low) IT-adopters" (Dadoukis et al., 2021; Liang & Qamruzzaman, 2022; Muneeb et al., 2022).

Financial disclosure quality (FDQ**):** following the existing literature (Abeysekera et al., 2021), the present study has constructed the financial disclosure quality indexed by accounting for accrual, persistence, predictability, and smoothness. In financial reporting, "earnings quality" may be broken into four categories. We evaluated the quality of each component of earnings using a scale that ranged from 1 to 10, with one being the least desired and 10 representing the ideal outcome. The quality, predictability, and smoothness of accruals are each assessed on an upward scale, with higher values indicating greater earning quality. A correlation between higher values and more predictability is also suggested, implying that the greater the consistent earnings, the lower the quality of the profits. The quality continues to deteriorate as the scale moves downward. This study calculated the Financial Disclosure Quality (FDQ) using the standardized, average aggregate score of the four assessed aspects (Dechow & Dichev, 2002; Li et al., 2014). This was carried out to ensure accuracy. There is no one approach to integrating the four earnings aspects that everyone recognizes and accepts.

$$\boldsymbol{FDQ_i = AQ_i^{1\,TO\,10} + PER_i^{1\,TO\,10} + PRED_i^{1\,TO\,10} + SMOOTH_i^{1\,TO\,10}}. \quad (1)$$

The accrual earning quality has been derived by executing the following equation:

$$TCA_{it} = a + b_1 CFO_{i,t-1} + b_2 CFO_{i,t} + b_3 CFO_{i,t+1} + c, \quad (2)$$

where $CFO_{i,t-1}$ stands for cash flows from operation in year t-1. $CFO_{i,t}$ stands for cash flows for the current period, and $CFO_{i,t+1}$ explains the cash flows for the next period.

The persistence equation is as follows:

$$\boldsymbol{EARN_{it} = a + b_{it} EARN_{i,t-1} + c}, \quad (3)$$

where $Earn_{j,t}$ is firm j's net income before extraordinary items in year t, $Earn_{j,\,t-1}$ is firm j's net income before extraordinary items in year t-1, and c is the residual. Through the use of the technique of persistent regression [49, 50], it is possible to deduce the predictability of profits by analyzing the variance in the residual value. Greater variations in the residual, as assessed by the square root of that variance, signal a lower degree of persistence. This is because the square root of that variance measures persistence.

The component of productivity and smoothness can be derived with the expectation of the following equation:

$$PRED_{it} = \sqrt{\delta^2 * c_{it}^{*}}, \quad (4)$$

where $PRED_{j,t}$ is the earnings predictability of firm j in year t, and σ2 ($\hat{c}$ j, t) is the estimated residual variance of firm j in year t, calculated from the following equation:

$$\text{Smoothness} = CFO_{it} / EARN_{i,t+1}. \quad (5)$$

Corporate governance: The term CG was originally used in the 1800s by Alabdullah et al. (2014) to bridge the gap between the management of the company and the owner-principal due to unacceptable managerial practices that might damage the firm. As a result, the CG idea was developed to account for the interrelationships between board members, management branch managers, audit committees, shareholders, and other interested parties. CG can be defined as the effective implementation of ethical guidelines and practices in the organization through control machinima (Alabdullah et al., 2014; Liang & Qamruzzaman, 2022). CG is a set of rules and methods that govern the relationship between management and stakeholders. It accomplishes this by providing corporate functions such as transaction transparency, legal compliance, shareholder protection, and business ethics. The impact of CG on a firm's performance varies with the appropriate selection of measurement, implying that appropriate proxy detection can produce diverse outcomes in empirical assessment (Al-Homaidi et al., 2019). Managers and authorities across the globe are using CG as a proxy for workers because of global financial problems (Sun et al., 2011). Following the existing literature (Nam & Lum, 2006; Siagian et al., 2007), we constructed a corporate governance index using the corporate governance checklist (Table 1).

TABLE 1 Measures of corporate governance index.

Corporate governance	Notion	Mechanism description	Measurement with supporting literature
Number of board meetings held	NBM	Total number of board meetings held.	Award 1 mark if the board meeting held in the firm i in year t is greater than the median value of the sample in fiscal year t, 0 mark otherwise (DEY, 2008; Shi & Qamruzzaman, 2022)
Female director	FD	If the board has female representation or not	Award 1 mark if firm I in fiscal year t has a female director on the board, 0 mark otherwise (Ararat et al., 2010)
Institutional ownership	IO	Measured as the ownership held by institutions in the firm	Award 1 mark if institutional ownership held in the firm i in year t is greater than the median value of the sample in a specific industry, 0 marks otherwise (Crane et al., 2016; Xia et al., 2022)
Number of committees established	NCE	The total number of committees a firm has	Award 1 mark if the committee established in the firm i in year t is greater than the median value of the sample in a specific industry, 0 mark otherwise (Crane et al., 2016)
Dividend payment	DP	Measured by the dividend per share	Award 1 mark if the dividend paid in the firm i in year t is greater than the median value of the sample in a specific industry, 0 marks otherwise (Easterbrook & Fischel, 1984; Qamruzzaman, 2022b)

Three control variables that may affect firm performance are added to the sample: FIRM SIZE, measured by the natural logarithm of total assets; LEVERAGE, measured by the ratio of total debts to total assets; and FIRM AGE, measured by the number of operating years since establishment. For details, see Table 2.

TABLE 2 Proxies of research variables.

Code	Variable name	Operationalization
Dependent variable: financial performance		
MVA	Market value added	Market value added = market value of the company − capital investment
SR	Stock return	The average return from closing price changes
ROE	Return on equity	Return on equity = net income/shareholder's equity
Independent variables		
ED	Environmental disclosure	The complete overview appraisal of the environmental issues disclosed by the company
FDQ	Financial disclosure quality	Environmental disclosure index
IT	Information technology adoption	Dummy variable 1 (0) if the bank is above (below) the median of the ratio
GG	Corporate governance	Corporate governance index
Control variables		
Firm size	Size of the total asset of the company	Ln (total assets)
Firm age	Length time of the firm's established	Ln (firm age)
Financial leverage	Debt to finance operating activities	Debt to equity ratio

4.2 The hypothesis of the study

1. Environmental disclosure positively fosters firms' financial performance.
2. Quality of financial disclosure prompts firms' financial performance.
3. IT adoption increases the possibilities of firms' performance sustainability.
4. Corporate governance is positively connected to firms' financial performance.

4.3 Regression models

To assess the aforementioned hypotheses of the study, the following regression models are to be implemented, where financial performance is measured by MVA, SR, and ROE with independent variables, namely, FD, ED, IT adoption (IT), and GG, along with a list of control variables: firm size (FZ), leverage (LEV), and firm age (AGE).

Model 1–03: without mediating effects

$$MVA_i = \beta_0 + \beta_1 FD_i + \beta_2 ED_i + \beta_3 IT_i + \beta_4 GG_i + \beta_5 SIZE_i + \beta_6 LEV_i + \beta_7 AGE_i + \epsilon_I.$$

$$SR_i = \beta_0 + \beta_1 FD_i + \beta_2 ED_i + \beta_3 IT_i + \beta_4 GG_i + \beta_5 SIZE_i + \beta_6 LEV_i + \beta_7 AGE_i + \epsilon_I.$$

$$ROE_i = \beta_0 + \beta_1 FD_i + \beta_2 ED_i + \beta_3 IT_i + \beta_4 GG_i + \beta_5 SIZE_i + \beta_6 LEV_i + \beta_7 AGE_i + \epsilon_I.$$

Model 04–06: with mediating effects

$$MVA_i = \gamma_0 + \gamma_1 FD_i + \gamma_2 ED_i + \gamma_3 IT_i + \gamma_4 GG_i + \gamma_5 (GG^*FD)_i + \gamma_6 (GG^*ED)_i + \gamma_7 (GG^*IT)_i + \gamma_8 SIZE_i + \gamma_9 LEV_i + \gamma_{10} AGE_i + \epsilon_I.$$

$$SR_i = \gamma_0 + \gamma_1 FD_i + \gamma_2 ED_i + \gamma_3 IT_i + \gamma_4 GG_i + \gamma_5 (GG^*FD)_i + \gamma_6 (GG^*ED)_i + \gamma_7 (GG^*IT)_i + \gamma_8 SIZE_i + \gamma_9 LEV_i + \gamma_{10} AGE_i + \epsilon_{I.}$$

$$ROE_i = \gamma_0 + \gamma_1 FD_i + \gamma_2 ED_i + \gamma_3 IT_i + \gamma_4 GG_i + \gamma_5 (GG^*FD)_i + \gamma_6 (GG^*ED)_i + \gamma_7 (GG^*IT)_i + \gamma_8 SIZE_i + \gamma_9 LEV_i + \gamma_{10} AGE_i + \epsilon_I.$$

5 Model estimation and discussion

5.1 Descriptive statistics and multicollinearity assessment

Table 3 exhibits the descriptive statistics of research variables. Referring to the measures of financial performance, the mean value of MAV is 4.561 per share with a standard deviation of 0.1542, the average ROE is 1.541 percent with a standard deviation of 0.2409, and for SR, the mean value is 5.7956 percent with a standard deviation of 0.1571. The mean value of environmental disclosure is 0.4919 with a standard deviation of 0.1425, the mean value of the financial disclosure quality index is 8.2749, and the standard deviation is 4.949. The average value of IT adoption is 0.4747 with a standard deviation of 0.1211. The corporate governance index's average value is 0.5441, and the standard deviation is 0.1366.

To explore the possible multicollinearity among the research variables, the study has implemented the pairwise correlation, and the results are presented in Table 4. According to the coefficient of correlation, it is shown that the issue of multicollinearity is not available. The coefficient value is less than the threshold, which is 0.80.

In addition, we conducted individual VIF studies for each incident. We found that none of the readings in any of them surpassed the

TABLE 3 Descriptive statistics of research variables.

	OBS	Mean	Std	Max	Min
MVA	1,500	4.561	0.1542	7.8452	−0.251
ROE	1,500	1.54	0.2409	2.632	−1.097
SR	1,500	5.7956	0.1571	8.1845	−0.0845
ED	1,500	0.4919	0.1425	1	0
FDQ	1,500	8.2794	4.949747	10	3
IT	1,500	0.4741	0.1211	1	0
CG	1,500	0.5441	0.13662	1	0
Age	1,500	41	11.33375	57	26
Size	1,500	21.86	1.244	28	17.64
Lev	1,500	0.413	0.203	0.903	0.046
NBM	1,500	0.6027	0.1323	1	0
FD	1,500	0.4518	0.1307	1	0
IO	1,500	0.6566	0.1534	1	0
NCE	1,500	0.4558	0.1348	1	0
DP	1,500	0.5553	0.1319	1	0

Note: market value added, MVA; stock return, SR; and return on equity, ROE with independent variables, namely, financial disclosure, FD; environmental disclosure, ED; IT adoption, IT; and good governance, GG, along with a list of control variables: firm size, FZ; leverage, LEV; and firm age, AGE.

threshold of 10. This was the case regardless of the situation (Shan, 2013). Results of VIF displayed in Table 5.

5.2 The effects of corporate governance, IT adoption, environmental disclosure, and financial disclosure quality on performance—market value added

The effects of technological adoption on firms' performance have been revealed to be positive and statistically significant for the full sample (a coefficient of 0.1609), banking institutions (a coefficient of 0.1668), and the insurance industry (a coefficient of 0.021). Considering the coefficients, it is apparent that information technology adoption has produced a friendly environment in augmenting financial performance. In particular, the effect of IT adoption is more significant in the banking industry than in insurance institutions. The study documented a positive and significant linkage between the effects of environmental disclosure on performance. More specifically, a 10% improvement in environmental disclosure accelerates the firms' market value performance by 0.168% for full-sample assessment, 0.293% for banking industry assessment, and 0.961% for insurance. A study advocated that environmental reporting for the insurance industry has a greater impact on firms' performance than the banking industry. The study established that the quality of financial disclosure positively accelerated the firms' performance; that is, financial transparency with the precision of financial information results in increase in the firms' value. In particular, a 10% improvement in the financial disclosure quality can improve financial performance by 0.351% for the overall assessment, 0.477% for the banking industry, and 0.769% for the insurance industry. Studies suggest that presenting financial information and access to all increase the organizational reputation and eventually support accelerating institutional performance. Our finding is supported by the existing literature (Al-Sartawi, 2018; Zhuo & Qamruzzaman, 2022). Disclosure of financial information is an unavoidable need for companies' prosperity since these establishments depend on providing truthful and up-to-date data to assist investors in making decisions and influencing new investors (Lipunga, 2014; Li & Qamruzzaman, 2022).

The coefficient of corporate governance on MVA revealed positive and statistically significant for the full-sample assessment (a coefficient of 0.0764), the banking industry (a coefficient of 0.0799), and the insurance industry (a coefficient of 0.0549). According to the assessment, effective governance in the organization ensures sustainability in financial performance, which is supported by the existing literature (Balasubramanian et al., 2010; Muhammad Sadiq et al., 2016; Hussain et al., 2019). Corporate governance ensures not only the trust of shareholders but also that of other stakeholders, such as 1) the government, 2) workers, 3) suppliers, and 4) consumers, by ensuring that the leaders of organizations are held responsible for the decisions they make. Shareholders are one example of a stakeholder group. Companies with inadequate governance have a larger propensity for worse operational performance and value, higher input costs, lower labor productivity, and lower equity return and value (Zaharia & Zaharia, 2012). On the other side, good corporate governance guarantees shareholders will obtain the maximum returns possible on their investments. This, in turn, contributes to an increase in total wealth and the economy's growth as a whole (Crețu, 2012; Qamruzzaman, 2022a).

The results of mediating effects of good governance on firms' performance are displayed in Supplementary Appendix Table S7. According to the coefficients of the interactive term (IT*CG, ED*CG, FDQ*CG), the study revealed a positive and statistically significant linkage between them, indicating the mediating role of corporate governance.

TABLE 4 Results of pairwise correlation.

	MVA	ROE	SR	ED	FDQ	IT	GG	Age	Size	Lev
MVA	1									
ROE	0.2971	1								
SR	0.178	−0.1199	1							
ED	0.2179	0.2543	0.2814	1						
FDQ	0.3247	0.1178	−0.0002	0.2282	1					
IT	0.1035	0.0169	0.0342	−0.0937	−0.1088	1				
GG	0.1212	−0.113	0.461	−0.0745	0.2303	−0.026	1			
Age	0.2655	−0.1452	0.3887	0.2994	−0.1021	0.4018	0.256	1		
Size	0.1997	0.0561	0.3093	0.0758	−0.1095	0.3323	−0.1376	0.0069	1	
Lev	0.4534	0.1992	0.4457	0.419	−0.1236	−0.0339	0.3042	0.2409	−0.0563	1

Note: market value added, MVA; stock return, SR; and return on equity, ROE, with independent variables, namely, financial disclosure, FD; environmental disclosure, ED; IT adoption, IT; and good governance, GG, along with a list of control variables: firm size, FZ; leverage, LEV; and firm age, AGE.

TABLE 5 VIF diagnostic.

Variable	VIF	Sqrt vif	Tolerance
MVA	2.397	1.548225	1.1046
ROE	1.828	1.352036	1.0806
SR	2.842	1.685823	0.9705
ED	3.334	1.825924	0.9923
FDQ	3.631	1.905518	1.0502
IT	2.423	1.556599	0.9992
GG	4.345	2.084466	1.1161
ED*CG	1.742	1.319848	1.0434
FDQ8CG	5.42	2.328089	1.0545
IT*CG	4.48	2.116601	1.1068
Size	4.067	2.01668	1.0075
Leverage	5.711	2.38977	1.0982
Growth	2.117	1.454991	1.0744
Firm	3.428	1.851486	1.0243

Note: market value added, MVA; stock return, SR; and return on equity, ROE, with independent variables, namely, financial disclosure, FD; environmental disclosure, ED; IT adoption, IT; and good governance, GG, along with a list of control variables: firm size, FZ; leverage, LEV; and firm age, AGE.

5.3 The effects of corporate governance, IT adoption, environmental disclosure, and financial disclosure quality on performance—ROE

Supplementary Appendix Table S8 exhibits the results of the financial performance measured by ROE. According to the target model coefficients, it is revealed that IT adoption, ED, FDQ, and CG-positive support increases the value of the firm, which ROE measures. The study finding is in line with that of existing literature (Shin, 2001; Beccalli, 2007; Kharuddin et al., 2010; Sabherwal & Jeyaraj, 2015). Referring to empirical model estimation with a full sample, the overall industry performance has revealed a positive association with IT adoption (a coefficient of 0.0711), environmental disclosure (a coefficient of 0.0871), the quality of financial disclosure (a coefficient of 0.1382), and corporate governance (a coefficient of 0.092). Furthermore, taking account of model estimation with the banking industry, the study revealed that the financial performance, that is, ROE, increases due to investment in IT integration (a coefficient of 0.0396), prompt disclosure dealing with environmental activities (a coefficient of 0.0472), the transparency in financial information accessibility (a coefficient of 0.0525), and the presence of effective corporate governance (a coefficient of 0.0404). The study revealed that IT adoption (a coefficient of 0.0712), ED (a coefficient of 0.0026), FDQ (a coefficient of 0.0326), and CG (a coefficient of 0.0722) act as catalysts in improving the financial performance in the insurance industry. On a comparative note, the insurance industry's financial performance has been revealed to be more significant than the banking industry's performance. In contrast, environmental disclosure and the quality of financial disclosure have been established as critical to improving the financial performance in the banking industry.

The next study implemented the empirical assessment with the mediating role of corporate governance on financial performance, measured by ROE. The results of mediating effects assessments are displayed in Supplementary Appendix Table S9. According to the coefficients of the interactive term, the study exposed positive and statistically significant effects running from (IT*CG) and (FD*CG) to the financial performance of the banking industry and the negative association documented for (EDQ*IT). Regarding insurance industry assessment, corporate governance's mediating effects have been positive and statistically significant, which is valid for all interactive-term investigations.

5.4 The effects of corporate governance, IT adoption, environmental disclosure, and financial disclosure quality on performance—stock return

In the following, financial performance is measured by taking into account the stock return, which is measured by the average monthly closing price. The results of the empirical estimation are displayed in Supplementary Appendix Table S10. According to the effects of explanatory variables on stock return, the study established a positive tie between IT adoption and stock return in the banking industry (a coefficient of 0.0528) and insurance industry (a coefficient of 0.0796), indicating that investment in IT boosts the firms' performance. The literature supports our study's finding of a positive linkage between IT adoption and stock return (Dewan et al., 2007; Lui et al., 2022; Squillace et al., 2022). One of the likely reasons for this is that the investments that consumers make in information technology are analogous to the expenditures that businesses make in that area. The likelihood of an increase in sales is thus rendered null and void because customers may use information technology to save costs while searching for low-cost goods or services and selecting alternative suppliers. Put another way, investments in information technology are necessary to keep up with the changes in the market; yet, these expenditures are not sufficient on their own to go ahead with these changes in the market. Because of this, a fall in the price that consumers pay for products or services may lead to a decline in profitability, although a decrease in input costs may increase overall levels of productivity.

The nexus of environmental disclosure and stock return was positive and statistically significant in the banking industry (a coefficient of 0.0822) and the insurance industry (a coefficient of 0.0403). The magnitudes of environmental disclosure were more significant for the banking industry than the insurance industry. Our study findings aligned with the existing literature (Rostami et al., 2016; Cahyani Putri, 2019; Suhadak et al., 2019; Alsahlawi et al., 2021). Better governance that includes an increase in financial and operational openness is one way, so the argument goes that the organization may attain a lower risk of adverse selection. Traders provide higher liquidity to the stocks of organizations with strong governance because these companies have fewer problems with adverse selection.

The study established that the quality of financial disclosure positively assists in increasing the stock return in the financial market. According to the study coefficient, a 1% development in the quality of financial disclosure will result from the acceleration of stock return in the banking industry by 0.207% and in the insurance industry by 0.202%. The elasticity of FDQ is almost equally likely. The literature supports the positive linkage between the quality of financial disclosure and stock return (Gao et al., 2016). However, it contrasts with the study findings of Hussein and Nounou (2021).

Corporate governance impact on stock return revealed a positive and statistically significant association. Referring to the coefficients, a 1% improvement in corporate governance practices can augment the stock performance by inducing the stock return of the banking sector by 0.124% and the insurance industry by 0.1299%, respectively. Study findings are supported by the studies of Amelia et al. (2021), Wicaksono and Wahyudi (2022), and Indijanto et al. (2022). Corporate governance encompasses "all those components which affect the organization's decision making" (Wicaksono & Wahyudi, 2022). It considers not only the control rights of shareholders but also the control rights and insolvency powers of those who hold the loans. In addition to that, it considers the commitment to the workforce, the suppliers, and the consumers in addition to the statutory and regulatory requirements. The extent of the degree of competition in the sector of the economy in which the firm operates has a sizeable effect on the decisions that are made by the company.

The next study implemented the empirical assessment with the mediating role of corporate governance on financial performance, which is measured by stock return. The results of mediating effects assessments are displayed in Supplementary Appendix Table S11. According to the coefficients of interactive term, the study exposed positive and statistically significant effects running from (IT*CG) and (FD*CG) to the financial performance of the banking industry and the negative association documented for (EDQ*IT). Referring to the insurance industry assessment, the mediating effects of corporate governance have been exposed as positive and statistically significant, which is valid for all interactive term investigations.

5.5 Robustness assessment of empirical output with system-GMM estimation

The study extended the empirical assessment by implementing the system-GMM framework with the motivation of robustness assessment. The results of the system-GMM assessment are reported in Table 6. The empirical model output was displayed in columns [1], [3], and [5] without interactive terms, and columns [2], [4], and [6] revealed empirical model output with the interactive term. Referring to the output displayed in columns [1], [3], and [5], the impact of TI adoption, environmental disclosure, the quality of financial disclosure, and corporate governance established a positive and statistically significant connection to financial performance. Furthermore, the interactive term, dealing with the assessment of moderating effects of corporate governance on firms' performance, according to the coefficient displayed in columns [2], [4], and [6], the positive and significant effects revealed and confirmed the mediating role of corporate governance in the empirical assessment.

6 Discussion

The study documented a positive and statistically significant association between corporate governance and the financial performance of the financial institutions, indicating that operational efficiency and transparency enhance the organization's reputation and market competitiveness and change the investors' perception on a positive note, eventually augmenting the performance of the firms'. Our findings align with existing literature (Alves & Mendes, 2004; Kula, 2005; Siagian et al., 2007; Boshnak, 2021; Ahmet et al., 2022). The study by Baek et al. (2004) established that the possibility of a conflict of interest between the principles of the organization and the agents of the organization might be mitigated, eventually resulting in an increase in the value of the business under efficient governance practice and ownership structure. Furthermore, according to Tomar and Bino (2012), the concept of "corporate governance" refers to the act of putting in place the structure, processes, and mechanisms that guarantee the company is being directed and managed in a manner that increases the firm's potential for long-term shareholder value by holding managers accountable and improving the company's

TABLE 6 Results of robustness assessment with system-GMM.

	[1]	[2]	[3]	[4]	[5]	[6]
MVA (−1)	0.1036 (0.01) [10.36]	0.1619 (0.0118) [13.7203]	—	—	—	—
ROE (−1)	—	—	0.1191 (0.0161) [7.3975]	0.1487 (0.0133) [11.1804]	—	—
SR (−1)	—	—	—	—	0.0872 (0.014) [6.2285]	0.156 (0.0143) [10.909]
IT	0.0113 (0.0175) [0.6457]	0.1219 (0.0146) [8.3493]	0.0474 (0.0179) [2.648]	0.0383 (0.0142) [2.6971]	−0.0099 (0.015) [−0.66]	0.017 (0.0134) [1.2686]
ED	0.015 (0.0108) [1.3888]	0.0499 (0.016) [3.1187]	−0.0788 (0.0174) [−4.5287]	−0.0653 (0.0105) [−6.219]	0.1566 (0.018) [8.7]	0.1395 (0.0162) [8.6111]
FD	0.1482 (0.012) [12.35]	−0.0511 (0.0136) [−3.7573]	0.0582 (0.0098) [5.9387]	−0.0115 (0.0158) [−0.7278]	−0.0217 (0.0158) [−1.3734]	−0.0816 (0.013) [−6.2769]
CG	0.0947 (0.0157) [6.0318]	−0.0827 (0.0106) [−7.8018]	0.0085 (0.0101) [0.8415]	0.0215 (0.0126) [1.7063]	0.1612 (0.01) [16.12]	−0.0622 (0.0163) [−3.8159]
IT*CG	—	0.0896 (0.0131) [6.8396]	—	0.0956 (0.0123) [7.7723]	—	−0.0395 (0.0179) [−2.2067]
FD*CG	—	0.1405 (0.0126) [11.1507]	—	0.0072 (0.0181) [0.3977]	—	0.0318 (0.0145) [2.1931]
ED*CG	—	0.1391 (0.0114) [12.2017]	—	0.1618 (0.0178) [9.0898]	—	0.0601 (0.0131) [4.5877]
Firm size	−0.06 (0.0172) [−3.4883]	0.1202 (0.0155) [7.7548]	0.1401 (0.012) [11.675]	0.0452 (0.0176) [2.5681]	0.0738 (0.0158) [4.6708]	−0.0012 (0.0117) [−0.1025]
Leverage	0.0431 (0.0134) [3.2164]	−0.0096 (0.0149) [−0.6442]	0.0987 (0.0099) [9.9696]	0.1274 (0.0137) [9.2992]	0.0246 (0.0179) [1.3743]	0.0824 (0.0132) [6.2424]
Firm age	−0.0713 (0.0184) [−3.875]	−0.0021 (0.0146) [−0.1438]	0.0687 (0.0179) [3.8379]	−0.0596 (0.0156) [−3.8205]	0.0111 (0.0181) [0.6132]	0.0039 (0.0142) [0.2746]
Year effects	Yes	Yes	Yes	Yes	Yes	Yes
AR(1)	0.0013	0.0061	0.0062	0.0065	0.0016	0.005
AR(2)	0.0938	0.8543	0.4973	0.6316	0.8241	0.8307
Hansen J-test	0.1095	0.6347	0.8809	0.179	0.2394	0.5847
Hansen test	0.4187	0.7476	0.9187	0.3887	0.3606	0.1355
Industry effects	Yes	Yes	Yes	Yes	Yes	Yes
Sample	75	75	75	75	75	75

Note: market value added, MVA; stock return, SR; and return on equity, ROE, with independent variables, namely, financial disclosure, FD; environmental disclosure, ED; IT adoption, IT; and good governance, GG, along with a list of control variables: firm size, FZ; leverage, LEV; and firm age, AGE. RE, random effects; FE, fixed effects; and OLS, ordinary least square.

overall performance. In other words, the interests of managers and shareholders may be brought into harmony *via* the implementation of such a framework by resolving the all-too-familiar "agency dilemma," which arises when ownership and management are kept separate.

IT adoption has been positively and statistically significant to the firm's sustainability, indicating the catalyst role of IT development in thriving financial performance. According to IT adoption elasticity in a firm's sustainability measures, a study advocated that a 10% technological development progress will result in performance acceleration. Our study findings are in line with existing literature (see, for instance, Horobet et al., 2021; Ghose and Maji, 2022), The information technology revolution has screwed up the conventional method of conducting business in the banking industry by making it possible for banks to break out of their comfort zones and the value creation chain. This has resulted in the old method being rendered obsolete. Because of this, the delivery of customer support may now be divided into several businesses. Therefore, as an example, the vast majority of banks that operate on the internet also offer insurance and securities in addition to banking goods. However, not all the items they distribute are manufactured by their organization (Hernando & Nieto, 2007).

Furthermore, it would seem that information technology opens up previously unimaginable prospects for the banking industry in terms of how they may arrange the creation, distribution, and marketing of financial products over the internet. While it presents the banking industry with new opportunities, it also ushers in a slew of difficult challenges, such as the development of novel IT applications, the erosion of traditional market demarcations, the breaking down of traditional industry barriers, the emergence of new competitors, and the introduction of novel business models (Saatcioglu et al., 2001; Liao

& Cheung, 2003). Le and Ngo (2020) provide evidence that the use of cutting-edge technology significantly contributes to improving a company's financial performance. The fact that the deployment of new software and online banking enhances the management of credit risk (Campanella et al., 2017), decreases the information cost access (Petria et al., 2015), and lowers the operational cost may be an explanation for the beneficial effect (Liberti & Petersen, 2018). The outcomes of this study were just published in the peer-reviewed journal Credit Risk Management (Dong et al., 2020).

According to the elasticity of environmental disclosure and firm performance, the study established a negative tie to stock return, demonstrating that a higher degree of environmental disclosure by firms translates to a lower stock return for enterprises listed in Bangladesh. Our finding is supported by the literature offered in the study of Alsahlawi et al. (2021), Brammer et al. (2006), and Hsu et al. (2017). One possible explanation for the adverse finding is that although environmental, social, and governance (ESG) policies might be value-relevant for investors and other stakeholders, these practices are not properly incorporated into stock returns. A further justification for the conclusion may be found in the argument about the risk factors. According to Mănescu (2011), the returns of businesses with low environmental factors are higher, primarily because these returns include a non-sustainability risk premium. It has been hypothesized that environmental, social, and governance factors might represent systemic risk. This is consistent with the increased knowledge of the potential for non-sustainability and the accessibility of information. As a result, the negative link between the environmental disclosure score and stock returns may result from the incentive offered for the risk of non-sustainability. This is a consequence of the fact that the disclosure score takes into account environmental factors. That is to say, companies that have a larger ED show less risk, and as a result, the stock returns will be lower in the event that they are invested in such companies. On the other hand, the study unveiled the positive effects of ED on a firm's performance which ROA and ROE measures. Our study findings are in line with those of the existing literature (Maji and Kalita, 2022).

7 Practical implication

The presence of effective corporate governance practices accelerated the growth of the firms, implying the active presentation of firms' strategies along with the way of execution by offering the intended direction of future development. Regardless of the interest of the target group's connection to the firms, accountability and transparency improve the organizational reputation and accelerate the growth of financial indicators. Furthermore, nowadays, most of the company's shareholders have shown an interest in being elected to the board of directors to assume responsibility for the organization's market position concerning its economic standing. As a direct consequence of the failure of several large organizations located worldwide, there has been a resurgence of focus on the performance and behavior of an organization's board of directors. The board of directors of the company, who are often among the most senior members of management, bears the whole weight of responsibility for the business's overall strategic direction. Effective corporate governance is analogous to having a very significant foundation, and it plays a part in the success of business ventures entrepreneurs run. Institutional investors favor companies with strong corporate governance structures, such as board independence, audit committees, and CEO duality, according to Baxter (2007). This is because these factors tend to reduce earnings management, which is a positive sign of the quality of financial disclosure. Institutional investors have several objectives, one of which is to ensure the truthfulness and transparency of financial disclosure and their conformity with the norms and standards of financial reporting. These norms and standards may include the International Accounting Standards (IAS).

The widespread use of the internet and the rise of the economy based on information contribute to the ever-increasing challenges we face today. The banking industry, on the other hand, needs to have a solid understanding of the nature of the changes that are occurring in their environment, specifically changes in terms of IT, innovation, and demographics, to properly deal with the challenge that is posed by IT. If one lacks this understanding, it may be impossible to transition into the information technology field successfully. In the modern-day, financial institutions that are well-prepared and have a strong grasp of the phenomenon of electronic banking will be in a better position to make intelligent decisions about how to convert IT and make the most of the potential of electronic banking. Establishing core competencies in today's highly competitive market may aid the banking sector in rearranging their products and service distribution to their customers. The shift from conventional banking to electronic banking will enable the sector to retain its competitive advantages and reach a state of unity.

8 Conclusion and policy recommendation

The motivation of this study is to assess the role of IT adoption, environmental disclosure, the quality of financial disclosure, and corporate governance on firms' financial performance, measured by MVA, ROE, and SR. The study considered a pool of 75 financial institutions with 30 representing the bank-based financial institutions and 45 representing the insurance industry. The pertinent data have been extracted from the publically annual report and stock data from Dhaka Stock Exchange for 2000–2019.

According to the empirical assessment, a study documented a positive and statistically significant link between explanatory variables and the measurement of financial performance. Furthermore, the moderating effects of corporate governance have been revealed with a positive indication. The study also implemented the system-GMM estimation in confirming the robustness by ensuring the association derived earlier with the target model.

The following suggestions are posted in future development on the concluding note that the study suggested: first, information asymmetry should be minimized and offer easy access to organizational information because accountability and transparency in the organization immensely guide firms' reputations and investors' commitment to the firms. Second, financial institutions in Bangladesh must encourage accepting technological innovation in their operational process to enable their financial services to be easily accessible through operational efficiency. Moreover, IT integration allows firms' to ensure accountability, and effective corporate governance supports the process of symmetry in information circulation. The eventual effects can be observed in the acceleration of financial performance. Thus, it is suggested that government incentives and policy support be offered in addition to capital investment so that the financial institutions have exploited the market opportunity. Third, protecting investors' interests is one of the critical factors contributing both positively and negatively. It suggests that investors' confidence might stabilize with good governance. Therefore, it is postulated that the management of FIs in Bangladesh should approach with positive intent, and governmental role in appropriate composition for management operation, in the long run, can support the firm's sustainability with persistent performance and investor's confidence.

The present study has the following limitations, which can be addressed in future research. First, the present study ignored the non-banking financial institutions in empirical assessment; therefore, a future study can be formulated with the inclusion of NBFIs of Bangladesh. Second, a future study can be initiated with the inclusion of diversified measures of financial performance such as net profit and earnings per share (EPS)

Data availability statement

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

Author contributions

MQ: Introduction: Methodology: Empirical model estimation; JL: Conceptualization, Discussion; First draft preparation, Final Preparation.

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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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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/fenvs-2023-1002357/full#supplementary-material

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ESG disclosure facilitator: How do the multiple large shareholders affect firms' ESG disclosure? evidence from China

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The Environmental, social, and governance (ESG) disclosure is an important aspect of firms' strategies. Therefore, exploring how to facilitate the firms' ESG disclosure is necessary. This paper examines the role of multiple large shareholders (MLS, hereafter) in facilitating a firm's ESG disclosure. Using a sample of Chinese listed firms during 2011–2020, we compare the ESG disclosure of firms having MLS with that of firms having a single large shareholder (SLS, hereafter) and find that having MLS associated with significantly higher ESG disclosure. After addressing endogeneity and altering the measurement of MLS, the benchmark results still hold after. Additional analysis shows that MLS exerts a more prominent positive effect on ESG disclosure in SOEs. We also examine the role of the other large shareholders in facilitating firms' ESG disclosure. Our findings reveal a bright side of MLS: it facilitates ESG disclosure by monitoring. Therefore, this paper's conclusion sheds new light on the bright side of MLS from the perspective of firms' ESG disclosure and provides insights into how to improve ESG disclosure.

KEYWORDS

ESG disclosure, multiple large shareholders, agency cost, ownership structure, monitoring effect, collusion effect, China

1 Introduction

Since the United Nations integrated environmental, social, and governance (ESG) in the Principles for Responsible Investment (PRI) in 2006, the ESG (Environment, Social, and Government) has drawn a lot of scholars' attention and become a hot topic in academia and practice (Siew et al., 2016; Li et al., 2020; Zhang et al., 2020; Li et al., 2021; Kolsi et al., 2022; Lu et al., 2022; Yoo and Managi, 2022). A growing strand of literature has examined the influence factors of ESG disclosure, such as corporate virtue (Christensen et al., 2022), board gender diversity (Manita et al., 2018), external natural disasters (Huang et al., 2022), and board structure (Husted and de Sousa-Filho, 2019). However, multiple large shareholders (MLS, hereafter) play a vital role in corporate governance through their intervention or "voice" on manager conducts and firm decision-making (Shleifer and Vishny, 1986; Dou et al., 2018). It is puzzling that there are a few scholars exploring the relationship between MLS and firms' ESG disclosure.

However, there have two strands that have emphasized the significant effects of MLS on firm behavior and have controversial conclusions. The first strand have investigated benefits of MLS extensively, such as the governance role in firms' investment decisions (Jiang et al., 2018), improving firm values by monitoring the insiders (Basu et al., 2016), improving financial reporting quality through their exit threat as informed investors (Dou et al., 2018). Boubaker et al. (2016) highlight the important governance role played by MLS in family firms. Boubaker et al. (2017) hold that MLS reduce the controlling owner's incentive to avoid bank monitoring, leading to greater reliance on bank debt. Boubaker et al. (2021) point that MLS play a governance role that neutralizes the effect of excess control on productive efficiency. The second strand have examined the cost sides of MLS. For instance, Jiang et al. (2020) hold that MLS is positively related to earnings management due to collusion and cost-sharing, which highlights a potential dark side of MLS. Moreover, MLS tend to collude and form an alliance to increase controllable profits when firms' behaviors are inconsistent with their interests (Zhang and Li, 2022). Therefore, whether MLS can facilitate firms' ESG disclosure still need to be further examined.

In China, on the one hand, MLS is a common ownership structure among listed firms and more than 30% of Chinese listed firms have at least large major shareholders that hold >10% of the shares (Cai et al., 2016). On the other hand, firms' ESG disclosure has been vigorously promoted and developed in China. In 2018, the Asset Management Association of China (AMAC) issued "the Green Investment Guidelines (For Trial Implementation)", which proposed the ESG disclosure framework for listed firms, thus requiring Chinese listed firms to disclose ESG information. The ESG disclosure system has accelerated the green transformation and development speed of Chinese listed firms, improved market transparency, and alleviated the problem of information asymmetry. Due to Chinese listed companies not only represent the driving force in ESG disclosure but also play a leading role in the Chinese ownership reform (Guo and Liang, 2016; Siew et al., 2016; Deng et al., 2022). This paper selected Chinese-listed firms as research samples for this study. Therefore, the context of China that provides an ideal environment for our research.

To further examine the impact of MLS on firms' ESG disclosure and explore its mechanism, we propose a hypothesis that firms with MLS may play a monitoring role in affecting their ESG disclosure based on the stakeholder theory and agent theory (Freeman, 1999; Esposito De Falco et al., 2021; Bhandari et al., 2022). Then, we collect Chinese listed firms' ESG disclosure scores during 2011–2020 from Bloomberg and manually identify whether a listed firm has more than one large shareholders or not each year during 2011–2020 based on the CSMAR database. Employing the variation between firms with MLS and firms with a single major shareholder (SLS, hereafter), this paper empirically estimates the impact of MLS on ESG disclosure based on the two-way fixed effect regression model. Baseline regression results show that having MLS increases ESG disclosure. To prove the robustness of the above finding, we also construct a difference-in-difference (DID, hereafter) model and find that our benchmark regression results still hold after considering the potential endogeneity problem. Our benchmark regression results are robust after altering the measurement of the MLS variable. Finally, we also explore mechanisms of firm ownership and the impacts of other large shareholders through additional analysis.

The main contributions of this study can be concluded in two aspects. First, this paper extend the studies on the influencing factors of ESG disclosure. Previous scholars focus on the impacts of ESG disclosure caused by managers' traits (Velte, 2019), board structure (Husted and de Sousa-Filho, 2019), and external environment shocks (Huang et al., 2022). We add to this strand of literature through solidly demonstrating the positive effects of MLS on ESG disclosure, which serve as a vital feature of corporate governance structure. Second, this paper deepen the understanding of the benefits of MLS, especially on firms' ESG disclosure, which unravels the bright side of MLS from the perspective of ESG disclosure. Previous studies have extensively emphasized the positive consequence of MLS, including alleviating agency problems (Edmans and Manso, 2011; Hope et al., 2017; Lin et al., 2020), and reducing managers' misconduct (Dou et al., 2018).

The remainder of this paper is: Section 2 is the theoretical analysis and hypothesis development. Section 3 provides the empirical design, including empirical models, sample selection, and variables. Section 4 provides baseline regression results and discussion. Section 5 conducts a series of robustness checks. Section 6 provides additional analysis. Section 7 provides conclusions and discussion.

2 Theoretical analysis and hypothesis development

Information asymmetry theory and stakeholder theory are the main theories employed in analyzing firms' ESG disclosure behavior (Mervelskemper and Streit, 2017; Billio et al., 2021). According to the information asymmetry theory, the firms' insiders generally hold more information than the external investors, which causes serious stock market information friction (Huang, 2021). ESG information disclosure can solve the information asymmetry problem between firms and investors so that investors can have a clearer perception of firm strategy from three dimensions: environment, society, and corporate governance (Duque-Grisales and Aguilera-Caracuel, 2021).

Meanwhile, the mainstream literature explains the driving force of ESG disclosure stakeholder theory (Freeman, 2001; 1999), which emphasizes that the purpose of ESG disclosure is simultaneously improving social and economic performance as well as fulfilling stakeholders' interests, such as customers, supplier, investors, employees, governments, and clients, which is not limited in chasing the maximum realization of shareholders' benefits (Esposito De Falco et al., 2021). Therefore, firms' ESG disclosure is conducive to demonstrating that firms actively prioritize social responsibility to stakeholders other than shareholders and create shared value for both parties while dealing with pressing social issues with creative solutions (Broadstock et al., 2021). In addition, firms' ESG disclosure exerts a significant impact on both their own value enhancement (Mervelskemper and Streit, 2017).

The shareholding structure is the logical starting point of corporate governance. The effect of major shareholders, as the key force in the internal governance of Chinese listed companies, on corporate information disclosure is currently dominated by two typical views in academia. On the one hand, some believe that MLS may have a "Collusion effect" on ESG disclosure. The controlling shareholders may conspire with management to make strategic disclosures to satisfy their interests, which has been revealed by the agency theory (Newton and Paeglis, 2019). Based on the tunnel effect theory, MLS may also conspire to exacerbate rather than mitigate agency problems (Guthrie and Sokolowsky, 2010). Cai et al. (2016) find that MLS also conspire to maximize their interests rather than monitor them if their interests are aligned, which harms firm value. Thus, MLS also tends to conspire to reduce ESG disclosure.

However, most existing literature considers the "effective monitoring effect" of MLS as the main role in corporate governance. At the theoretical level, the threshold effect of equity checks and balances is a common basis of analysis. The theory points out that MLS can not only guarantee the concentration of the company's equity, but also use the role of mutual supervision, checks, and balances, and competition between them to check the decision-making behavior of controlling shareholders, so as to reduce the encroachment of interests of controlling shareholders on listed companies. At the practical level, existing studies using empirical tests with data from several countries show that multiple majority shareholder shareholding structures can play a "monitoring effect". That is to say, the shareholding structure of MLS restrains management decisions, reduces corporate agency costs, and mitigates corporate information asymmetry. When a firm with MLS, collusion between controlling shareholders and manager is more costly because MLS not only monitor and check controlling shareholders and manager, but also improve internal control quality (Zhang and Li, 2022). Thus, MLS reduces the possibility of collusion and improves the efficiency of corporate governance (He et al., 2022).

Most of the existing studies have proved the view of the monitoring hypothesis. Based on the above analysis, this paper argues that the role of the monitoring effect of MLS is the main influence on the degree of corporate ESG disclosure. Specifically, multiple major shareholders, as the shareholder of corporate interests, have sufficient motivation to maintain the development of the company. The existence of MLS can monitor and check each other, thus effectively curbing managers' manipulation of corporate information for their own selfish interests and thus positively promoting corporate ESG information disclosure. Thereupon, this paper proposes the following hypothesis.

H1 (Monitoring effect): Firms with MLS increase their ESG disclosure, ceteris paribus.

3 Empirical research and methodology design

3.1 Sample selection and data sources

We choose the Chinese listed firms during 2011–2020 as the sample and conduct the following processes: (1) because the leverage of financial listed firms is abnormal, we exclude firms belonging to the financial industry; (2) because the operation and financial situation of ST* and ST listed firms is abnormal, we drop firms belonging to ST*, ST. The ESG disclosure of Chinese listed firms collected from Bloomberg, and other firms' financial and governance information are obtained from the CSMAR database. In addition, we also report industry sector distribution of Sample in Supplementary Table SA1 in Supplementary Appendix SA.

3.2 Variables construction

3.2.1 ESG disclosure

ESG disclosure published by Bloomberg has been broadly used in ESG disclosure literature recently (Siew et al., 2016; Minutolo et al., 2019). The ESG disclosure score of Chinese listed firms published by Bloomberg was employed to measure ESG disclosure. A higher score indicates a better ESG disclosure.

3.2.2 Multiple large shareholders

Following related literature (Jiang et al., 2020; Zhang and Li, 2022), we define Multi as a dummy variable measured by whether a firm has more than two large shareholders. The *Multi* dummy variable is equal to one if the firm has more than one shareholder and 0 otherwise. We consider that shareholders who individually or collectively hold >10% of the firm's shares have the right to request that the board of directors hold an extraordinary general meeting according to the Company Law of the People's Republic of China. Therefore, we define shareholders holding >10% of the shares as large shareholders.

3.3 Model specification

To empirically explored the impacts of MLS on ESG disclosure, we construct our baseline regression model based on related literature as follows (Jiang et al., 2020; Zhang and Li, 2022).

$$ESG_{i,t} = \alpha + \beta_1 \times Multi_{i,t} + \delta \times CVs_{i,t} + \theta_t + \delta_i + \epsilon_{i,t} \quad (1)$$

Where $ESG_{i,t}$ represents ESG disclosure of firm i at year t. $Multi_{i,t}$ denotes whether the firm i has more than two large shareholders at year t or not. We follow related literature (Basu et al., 2016) and define $CVs_{i,t}$ as the set of control variables containing *Bm*, *Duality, Indep*, *Board*, *Age*, *Soe*, *Roa*, *Size*, which were reported in Table 1. θ_t and δ_i represent time fixed effects and industry-fixed effects, respectively. $\epsilon_{i,t}$ is the error term. In addition, this paper cluster standard errors at the industry level. Table 1 report descriptions of main variables.

3.4 Summary statistics

Table 2 reports summary statistics of the main variables. We find that the proportion of listed firms with more than two shareholders is 26.4%, according to Table 1. The standard deviation of *ESG* is 6.977, the minimum value is 1.240, and the maximum value is 64.115, indicating a large variation in ESG disclosure among Chinese listed firms. The mean of *Duality* is 0.2, indicating that 20% of the sample firms have a CEO who is also the chairman. The mean of *Soe* is 0.504, indicating that 50.4% of the sample firms are state-owned. In addition, all sample distributions are consistent with extant research (He et al., 2022; Zhang and Li, 2022). In addition, we also report Correlation coeffcient matrix in Supplementary Table SB1 in Supplementary Appendix SB.

4 Benchmark regression results

Table 3 reported the regression results of baseline models (1). Columns (1)–(2) show that the variable of MLS (*Multi*) is 1% significantly positively associated with corporate ESG disclosure (*ESG*) and with estimate coefficients of 2.418 and 1.869, respectively. Therefore, the above baseline empirical finding proved the H1a, which indicates that having MLS increases corporate ESG disclosure (monitoring effect). Based on the estimation result in Column (2) of Table 3, we find that a one-standard-deviation increase in *MLS* raises a firm's ESG disclosure score by 0.822 points, which is obtained by multiplying the standard deviation of the *MLS* measure by the estimated coefficient.

TABLE 1 Variables definitions.

Variable	Definition
ESG	ESG disclosure scores published by bloomberg
Multi	A dummy variable is equal to 1 if the firm has more than two shareholders and 0 otherwise
Bm	The market value of equity divided by the book value of equity
Duality	A dummy variable equal to 1 if the CEO is also the chairman of the board, and 0 otherwise
Indep	The ratio of the number of independent directors to the number of board directors
Board	Log of number of board of directors
Age	Log of number of years after the firm's established
Soe	A dummy variable equals 1 if the firm is a State-owned enterprise, and 0 otherwise
Roa	The ratio of net profits relative to total assets
Size	Log of total assets

Notes: This table reports variable definitions.

TABLE 2 Descriptive statistics.

Variables	N	Mean	SD	Min	Median	Max
ESG	8,569	20.397	6.720	1.240	19.835	64.115
Multi	8,569	0.263	0.440	0.000	0.000	1.000
Bm	8,569	1.400	1.577	0.030	0.863	15.712
Duality	8,569	0.201	0.401	0.000	0.000	1.000
Indep	8,569	0.375	0.057	0.182	0.364	0.800
Board	8,569	2.182	0.204	1.099	2.197	2.996
Age	8,569	2.863	0.353	0.693	2.944	3.807
Soe	8,569	0.506	0.500	0.000	1.000	1.000
Roa	8,569	0.049	0.067	−0.645	0.040	0.675
Size	8,569	23.058	1.345	19.447	22.933	28.509

Notes: This table reports summary statistics of the sample. Our sample contains the firm-year observations of Chinese listed firms during the period 2010–2020.

Considering that the mean of ESG disclosure is 20.397, this effect is also economically significant.

In addition, we also find that the estimated coefficient of power concentration (*Duality*) is negative at the 5% siginificance level, which reflects that the power concentration (*Duality*) exerts a negative effect on ESG disclosure. We also find that the estimated coefficient of stated-owned enterprise (*Soe*) is positive at the 1% siginificance level, which indicates that the stated-owned enterprise (*Soe*) exerts a positive effect on ESG disclosure. We also find that the estimated coefficient of firms' age (*Age*) is positive at the 5% siginificance level, which indicates that the firms' age (*Age*) exerts a positive effect on ESG disclosure. We also find that the estimated coefficient of firms' size (*Size*) is positive at the 1% siginificance level, which indicates that the firms' size (*Size*) exerts a positive effect on ESG disclosure. In addition, we also find that the above finding still robust after controlling firm fixed effect in the benchmark model. The related results are reported in Supplementary Table SC1 in Supplementary Appendix SC.

5 Robustness checks

5.1 Mitigating potential endogeneity problem: DID estimations

Considering higher ESG disclosure is potentially related to the urgent need of MLS aiming at reducing agency cost and exerting a monitoring role in facilitating ESG disclosure. To solve the above potential endogeneity concern, following related literature (Slaughter, 2001; Zhang and Li, 2022), we define the treatment group as firms whose ownership structure once changed in sample period and the control group as firms whose ownership structure remained unchanged in sample period. Specifically, if firms whose ownership structure changed from an SLS to MLS in sample period are used as the treatment group, we define firms whose ownership structure has been an SLS all time in sample period as the control group. If firms whose ownership structure changed from MLS to an SLS in sample period are defined as the treatment group, we define the firms whose ownership structure has

TABLE 3 Baseline regression results.

Variables	*ESG* (1)	*ESG* (2)
Multi	2.418***	1.869***
	(0.504)	(0.286)
Bm		−0.240
		(0.148)
Duality		−0.584**
		(0.203)
Indep		2.159
		(3.930)
Board		−0.131
		(0.570)
Age		1.414**
		(0.515)
Soe		1.320***
		(0.272)
Roa		1.452
		(1.113)
Size		2.006***
		(0.209)
Year F.E.	√	√
Industry F.E.	√	√
N	8,569	8,569
Adjusted R^2	0.124	0.273
F-statistics	23.621	187.044

Notes:*, ** and *** indicate significant at the 10%, 5% and 1% levels, respectively. Values in parentheses are clustering standard errors at the industry level. Regressions have constant terms but are not shown. Other tables' notes are also the same as the above notes.

TABLE 4 DID estimation results.

Variables	Change from SLS to MLS	Change from MLS to SLS
	ESG (1)	*ESG* (2)
Change	0.994***	−2.667***
	(0.312)	(0.636)
Controls	√	√
Year F.E.	√	√
Industry F.E.	√	√
N	5,177	5,177
Adjusted R^2	0.195	0.195
F-statistics	83.121	406.578

Notes:*, ** and *** indicate significant at the 10%, 5% and 1% levels, respectively. Values in parentheses are clustering standard errors at the industry level. Regressions have constant terms but are not shown. Other tables' notes are also the same as the above notes.

TABLE 5 Alternative measurements of MLS to verify the robustness.

Variables	*ESG* (1)	*ESG* (2)
Multi	1.119***	1.059***
	(0.139)	(0.128)
Controls	×	√
Year F.E.	√	√
Industry F.E.	√	√
N	8,646	8,646
Adjusted R^2	0.106	0.266
F-statistics	64.622	216.811

Notes:*, ** and *** indicate significant at the 10%, 5% and 1% levels, respectively. Values in parentheses are clustering standard errors at the industry level. Regressions have constant terms but are not shown. Other tables' notes are also the same as the above notes.

TABLE 6 The role of other large shareholders.

Variables	*ESG* (1)	*ESG* (2)
Num	1.797***	1.465***
	(0.342)	(0.226)
Controls	×	√
Year F.E.	√	√
Industry F.E.	√	√
N	8,569	8,569
Adjusted R^2	0.119	0.271
F-statistics	27.643	177.054

Notes:*, ** and *** indicate significant at the 10%, 5% and 1% levels, respectively. Values in parentheses are clustering standard errors at the industry level. Regressions have constant terms but are not shown. Other tables' notes are also the same as the above notes.

TABLE 7 The role of SOE.

Variables	*Non-SOE*	*SOE*
	ESG (1)	*ESG* (2)
Multi	0.941***	2.710***
	(0.279)	(0.402)
Controls	×	√
Year F.E.	√	√
Industry F.E.	√	√
N	4,236	4,333
Adjusted R^2	0.196	0.299
F-statistics	133.142	74.181

Notes:*, ** and *** indicate significant at the 10%, 5% and 1% levels, respectively. Values in parentheses are clustering standard errors at the industry level. Regressions have constant terms but are not shown. Other tables' notes are also the same as the above notes.

been MLS all time in sample period as the control group. We construct DID model (2) as follows:

$$FEPU_{i,t} = \alpha + \beta \times Change_{i,t} + \delta \times CVs_{i,t} + \theta_t + \delta_i + \epsilon_{i,t} \quad (2)$$

In model (2), $Change_{i,t}$ is the dummy variable denotes whether a firm i changes from SLS (MLS) to MLS (SLS) at t year. Related results reported in Table 4 show that FEPU not only increases along with the firm changes from SLS to the model of MLS but also decreases along with firm changes from MLS to the model of SLS.

5.2 Alternative measurements of multiple large shareholders

Furthermore, we follow related literature (Zhang and Li, 2022) and define shareholders holding >5% of the shares as large shareholders and reconstruct *Multi* variable for the robustness test. The robustness regression results reported in Table 5 are still consistent with our baseline regression results.

5.3 Propensity score match (PSM)

Following the related literature (Jiang et al., 2020), to compare ESG disclosure of firms with MLS to that of a (propensity score) matched sample of firms with a SLS that have similar firm-level observable characteristics, we first use a logit model to estimate the probability (i.e., the propensity score) that a firm has MLS as a function of all of the firm characteristic variables in our baseline regression, with firm fixed effects and year fixed effects included as well. Next, we match each firm with MLS to a firm with a SLS based on a predicted probability difference within 0.0001 (in absolute value) from the probability of the MLS firm. The regression result of PSM is reported in Supplementary Table SD1 in Supplementary Appendix SD and shows that MLS exert a significant negative effect on firms' ESG disclosure. Our benchmark results still hold.

6 Mechanism analysis

6.1 The role of other large shareholders

Following related literature (Jiang et al., 2018), we use the number of large shareholders other than the first largest shareholder (*Num*), which aims to further analyze the effect of MLS.

In column (1) of Table 6, the coefficient of *Num* is 1.797 and significant at the 1% level, revealing that the number of other major shareholders positively affects firms' ESG disclosure; In column (2), the coefficient of *Num* is 1.465 and significant at the 1% level, also implying the above finding.

6.2 The role of agency cost

The State-owned enterprises (SOEs) are an important determinant of agency cost (Ding et al., 2018). Due to the lack of shareholders' supervision of managers, agency cost is higher in SOEs than Non-SOEs (Khuong et al., 2022). Therefore, we re-estimate baseline model (1) based on the subsample of "SOE" and "Non-SOE". Table 7 reports related results as follows. As shown in Table 7, the effect of MLS on ESG disclosure varies across ownership and MLS play a more positive role in facilitating ESG disclosure in SOEs. The reason is that for SOEs, MLS alleviate agency problem in SOEs more prominently by play a monitoring role, which facilitate firms' ESG activities disclosure.

7 Conclusion and discussion

Now, corporate ESG disclosure has been a worldwide concern, especially in developing countries like China. At the same time, MLS are important to firms' decision-making and strategy behaviors. This paper seeks to investigate whether a firm with MLS may form monitoring (collusion) and will increase (decrease) its ESG disclosure. Then, we find that having MLS increases corporate ESG disclosure. The above finding is robust to a series of robustness checks such as difference-in-difference (DID) estimation and altering the measurement of the variable of MLS. Finally, we also find that baseline results also vary across firm ownership and explore its mechanism of the role of other large shareholders. Therefore, this paper's conclusion sheds new light on the bright side of MLS from the aspect of ESG disclosure and provides insights into how to improve corporate ESG disclosure.

First, firms should notice the ownership structure and rational reform the ownership structure of listed firms. Specifically, firms should pay attention to the issue of equity concentration and strengthen the constraints on the first large shareholder. Besides, the firm should allow other large shareholders and minority shareholders to reflect the role of supervision and checks and balances, which can be done by enabling like-minded minority shareholders to participate in corporate decision-making through concerted action. Firms should actively undertake social responsibility and take the initiative to disclose ESG information to show the capital market the firms' good corporate image and attract green investment.

Second, the government should be aware of the supervisory role played by the MLS in corporate governance. Moreover, it can guide enterprises through policy formulation to actively attract strategic investment and improve corporate equity allocation and structure. Related government departments should gradually improve the ESG disclosure efficiency of listed firms and guide the ESG disclosure of Chinese listed firms to change from voluntary to mandatory disclosure gradually. The government should guide enterprises to make a smooth transition and gradually realize mandatory disclosure of ESG information under the guidance of laws and regulations.

Finally, this paper did not assess the impact of MLS on firms' ESG disclosure in different regions. In the future, we could take various regional heterogeneity into consideration and re-examine the influence of MLS on firms' ESG disclosure.

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

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

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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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2023.1063501/full#supplementary-material

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Green supply chain management, risk-taking, and corporate value—Dual regulation effect based on technological innovation capability and supply chain concentration

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With the promotion of carbon-peak and carbon-neutral strategies and the increase in green awareness, green development is gradually gaining attention, and the green supply chain management (GSCM) derived from traditional supply chain management is gradually becoming a path to promote green development. At the same time, enterprise, as an important source of pollution, how to consider social responsibility, such as environmental protection, in the process of ensuring efficiency improvement has become an important issue. To study the impact of green supply chain management on enterprise value and its path of action, this paper examines the impact of green supply chain management on enterprise value, explores the moderating effect of the risk-taking level, and further analyzes the dual moderating effect played by technological innovation capability and supply chain concentration. Based on the micro data of 131 Chinese listed enterprises from 2014 to 2021, a panel-regression model is used to illustrate how green supply chain management affects enterprise value, and the results show that: 1) green supply chain management can promote enterprise value; 2) the level of risk-taking strengthens the promoting effect of green supply chain management on enterprise value enhancement; and 3) the technological innovation capability negatively regulates the moderating effect of risk-taking, while the supply chain concentration positively regulates the moderating effect of risk-taking. The research results of this paper enrich the path of the effect of implementing of green supply chain management on enterprise value enhancement, i.e., the process of green supply chain management to enhance enterprise value is regulated by the level of enterprise risk-taking, while technological innovation capability and supply chain concentration will also regulate the level of enterprise risk-taking and thus promote enterprise value enhancement. This research not only extends the research perspective and enriches the existing research, but also provides a theoretical basis for enterprises to implement green supply chain management to promote value enhancement and improve the level of green supply chain management implementation and the green development of enterprises.

KEYWORDS

green supply chain management, risk-taking, enterprise value, technological innovation capability, supply chain concentration

1 Introduction

In the past forty decades, China's industrialization has developed rapidly and achieved a leap from the early stage of industrialization to the late stage of industrialization and has become the world's largest newly industrialized country and the second largest economy (Aslam et al., 2021), with achievements that have attracted worldwide attention. However, the problems of high emissions and pollution brought by economic development should not be underestimated (Chen, 2015). For example, air pollution due to PM2.5, soil pollution due to heavy metals and the continuous emission of carbon dioxide into the atmosphere during production and living activities have accelerated the process of global warming and caused a series of ecological problems and extreme weather (Mannucci and Franchini, 2017; Qin et al., 2021; An and Zhu, 2022), which not only affect human survival but also gradually affect the healthy economic development (Feng et al., 2021; Wei et al., 2023).

In the context of the destruction of ecological environment, the continued impact of COVID-19, and the increasingly severe situation at home and abroad, China's economic development is transforming from high-speed growth to green and high-quality growth, and enterprises are transforming from pursuing profits to pursuing benefits and how to achieve the coordinated development of economic capacity enhancement and ecological environmental protection has become an important issue (Sun et al., 2022).

In October 2020, Xi Jinping proposed unswervingly implementing the concept of green development and follow the path of green development. In October 2022, Xi Jinping proposed to promote green development and the harmonious coexistence of humans and nature. In addition, various countries and organizations have been enacting laws and regulations to protect the ecological environment (Wang et al., 2018). For example, the signing of the Paris Climate Agreement and the implementation of China's green credit policy (Zhang et al., 2022), carbon neutral strategy, carbon peak strategy, and Made in China 2025 (Xu, 2022). Because the concept of "green" is linked with "sustainability," or "eco" (Ezuma et al., 2022), thus these assertions and regulations have led to the green development approach represented by green supply chains, sustainability transitions (Sarkis et al., 2020), corporate initiatives for environmental responsibility (Li et al., 2020; Liao et al., 2021; Li et al., 2022), etc., which has received wide attention from various social parties (Tseng et al., 2019; Becerra et al., 2021; Pal et al., 2023). This includes government, public (Baldini et al., 2018), investors, and competitors (Cao et al., 2019). Along with the increasing public awareness of environmental protection and the introduction of government laws and regulations, enterprises, as one of the main sources of environmental pollution and also an important pillar of economic development (Panigrahi et al., 2018), have to reduce pollutant emissions and enhance green development through sustainable transformation, green technological advancement, green supply chain management (GSCM) and other green development approaches (Abu Seman et al., 2019).

GSCM is a comprehensive environmental management tool that has a greater potential to solve environmental problems, promote healthy business development of enterprises (Sheng et al., 2022), optimize resource efficiency and reduce environmental problems. The implementation of GSCM can lay the foundation for the development and realization of a green economy from a microscopic perspective, GSCM is becoming an inevitable choice to promote ecological civilization and solve environmental problems (Cao and Zhang, 2022). Therefore, in the context of the increasingly severe development situation of enterprises and the urgent need for green development, the creation of a green industrial chain and supply chain becomes a necessary condition for the improvement of enterprise competitiveness.

But under what circumstances will companies proactively implement and operate well with GSCM as a strategy, what impact will the implementation of GSCM have on corporate value, and in what ways will that impact be realized? These questions are yet to be explored in depth. For example, we should recognize that in the development of business operation, the level of risk-taking is also an extremely important point that affects the business decision process, the level of corporate risk-taking refers to the ability or level of risk that a company can take in the course of its business, specifically including operational risk and financial risk, only when the level of risk-taking is high, enterprises will make decisions such as GSCM to promote value enhancement and at the same time, technological innovation capability (TIC) and supply chain concentration (SCC) will affect the level of risk taking. Specifically, TIC is a new technology or capability that is modified or developed by an enterprise to achieve a certain goal or meet the needs of a certain activity, especially at this stage of China's economic transformation, the ability to innovate in technology is particularly important (Wang et al., 2021). The relationship between technology and economics has been the focus of much research (Liu et al., 2022a), many studies have mentioned that technological innovation activities have the characteristics of high investment and high risk (Lu et al., 2020; Liu et al., 2022b; Mao et al., 2022), and it is difficult to generate effective returns in the short term (Aghion et al., 2013), therefore, the higher the TIC, the more it can indicate the current technological innovation activities of the enterprise, the more it is not conducive to the stability of the enterprise's capital, which will enhance the enterprise's risk-taking level. SCC is an important indicator of the stability of the supply chain network in which an enterprise is located, including customer concentration and supplier concentration. The higher the concentration of the supply chain, the more stable the relationship between the enterprise and its suppliers and sellers, which to a certain extent can enhance the risk-taking level of the enterprise.

Therefore, this paper will take the level of risk-taking of a company as a research perspective to explore how GSCM affects corporate value when the level of risk-taking of a company varies. The significance of this study is that, firstly, from the theoretical point of view, this study deepens the research on the impact of GSCM on enterprise value, and further enriches and expands the research on the impact of GSCM on enterprise value from the perspective of enterprises' risk-taking level. Secondly, from the practical point of view, the research results of this paper can provide certain inspiration for enterprises to implement GSCM, and also to implement the green development approach represented by GSCM.

Based on this, this research explores how GSCM affects firm value when firms have different levels of risk-taking, and helps firms to further understand and implement GSCM. Specifically, the contribution points of this paper, 1) using micro-firm data rather than data from questionnaires to argue for a facilitating effect of GSCM on firm value; 2) finding that the higher the level of corporate risk-taking, the more the implementation of GSCM can promote firm value; 3) the lower the TIC and the higher the SCC, the higher the level of risk-taking, the more significantly GSCM can influence the enhancement of firm value. The research in this paper helps to supplement the research on GSCM and enterprise value in depth and can further provide theoretical support and empirical evidence for the implementation of GSCM in enterprises.

The remaining structure of this paper is organized as follows. Based on previous studies, Section 2 provides the literature review about GSCM. Section 3 presents a theoretical analysis and hypotheses on the impact of GSCM on firm value and its possible paths of action. Section 4 includes the models, data and their sources used in the paper. Section 5 empirically tests the direct, moderating and dual moderating effects of GSCM on firm value. Section 6 summarizes the paper's research, and Section 7 discusses the policy recommendations. Finally, Section 8 points to future research directions.

2 Literature review

2.1 Supply chain management and green supply chain management

Since the 21st century, competition has shifted from inter-organizational to inter-supply chain, and effective supply chain management practices have become a way to maintain a competitive advantage and improve business performance (Li et al., 2006). In the context of increasing economic globalization and the continued impact of the COVID-19, supply chain networks and their partnerships are facing many challenges and there is a risk of disruption (Wang and Yang, 2022). The outbreak, represented by COVID-19, has had a significant impact on all processes of each supply chain (Moosavi et al., 2022). As a result, we found that the traditional supply chain development model is more brittle and unable to meet the growing needs of companies (Sarkis et al., 2020).

Since the traditional supply chain management ignores the negative impact that the supply chain may cause to the environment in the process of operation and optimization (Gurel et al., 2015), GSCM or Environmental Supply Chain Management (ESCM) is based on traditional supply chain management, and focuses more on the efficiency of resource utilization and the environmental impact of enterprises in the supply chain, including suppliers, manufacturers, sellers, and end customers (Rabbi et al., 2020; Li and Zhou, 2022). Rodríguez-González et al. (2022) explored the impact of circular economy on corporate financial performance and found that circular economy contributes to GSCM practices and thus to corporate financial performance.

2.2 Sustainable supply chain management

With the increase of economic development, social progress and environmental protection awareness, the consideration of green sustainability and recyclability of supply chains in supply chain networks has gradually received wide attention from researchers. In order to achieve economic, social, and environmental sustainability, Panigrahi et al. (2018) provide a review and analysis of the theory of sustainable supply chains from economic, environmental and social perspectives. Salehi-Amiri et al. (2021) designed a sustainable closed-loop supply chain for the walnut industry. Yontar and Ersöz (2020) argue that the purpose of developing a green and sustainable supply chain is to provide, improve or enhance environmental and economic value for the various stakeholders in the chain. Zhu and Wu (2022) studied the impact of supply chain sustainability on supply chain performance, and found that supply chain sustainability can contribute to supply chain performance improvement, and supply chain sustainability plays a mediating role in the process of supply chain resilience affecting supply chain performance. Gholian-Jouybari et al. (2023) designed a sustainable supply chain for agri-food products by considering the concept of marketing.

2.3 Closed-loop supply chain and reverse logistics

With economic, social and environmental influences, business operations and decision makers are also considering closed-loop supply chains. Compared to traditional supply chains, closed-loop supply chains have more advantages, such as considering both forward and backward logistics (reverse logistics) (Liao et al., 2020), controlling waste emissions in the logistics cycle, etc., which can reduce the environmental damage and negative impacts of companies' supply chain activities (Chiu et al., 2021), it ensures that many industries are green and sustainable (Salehi-Amiri et al., 2021). Mirzagoltabar et al. (2021) proposed two new heuristic algorithms to study multi-objective dual-channel closed-loop supply chains considering the case of demand and price uncertainty and justified and tested them with the lighting industry. Asghari et al. (2022) studied the decision making problem of pricing and advertising in a closed-loop supply chain network. Xu et al. (2022b) incorporates overconfidence and competitive preferences into a closed-loop supply chain study and proposes a series of Stackelberg models with multiple dominant models, exploring how the chain of behavioural preferences jointly affects the pricing, profit, utility and social benefit decisions of both parties under different dominant models.

Reverse logistics is not only part of the closed-loop supply chain, it is also one of the most important processes in the green supply chain management framework (Rao and Holt, 2005). Through recycling, reuse and waste reduction scarce resources can be used efficiently and pollutant emissions can be reduce. Richnák and Gubová (2021) provides practical recommendations for the development of green and reverse logistics in Slovakian companies based on summarising and sorting out the research on green and reverse logistics. Ma et al. (2022) studied the impact of blockchain technology plays a role in the process of product recovery and distribution. Li and Chen (2022) designed a reverse logistics network for third party logistics under uncertainty disruption based on a risk-averse model. Based on blockchain technology, Wu (2022) proposes a commodity traceability solution that can effectively reduce waste generation and can provide for the sustainable development of green reverse logistics.

2.4 Green supply chain management and enterprise value

Enterprises are micro subjects of economic development, and important subjects of supply chain nodes. The role of GSCM in the development of enterprise operation is gradually becoming obvious. In the study of GSCM and firm value, Longoni and Cagliano (2018), Li et al. (2019), Ahmed et al. (2020) and Samad et al. (2021) concluded that GSCM can promote firm value.

Min and Galle (2001) found that green procurement increases firms' costs and inhibits improvement in their financial performance. Ni and Sun (2019) argued that GSCM might have a specific impact on firm value under certain conditions. To deeply explore the relationship between the two, Feng et al. (2018) and Abdallah and Al-Ghwayeen (2019) analyzed the mediating role played by environmental performance and operational performance in the process of GSCM affecting corporate financial performance. Zhang et al. (2019a) explored the role of social control in GSCM practices for corporate value enhancement based on social exchange theory. Sheu and Chen (2012) used a three-stage game theory model to analyze the role of government financial intervention in GSCM affecting firm value as a facilitator. Agyabeng-Mensah et al. (2020) argued that implementing green human resource management and supply chain environmental cooperation may contribute to the impact of internal GSCM practices on firm value. Fasan et al. (2021) studied the impact of the implementation of GSCM on the financial performance of companies in the context of the ongoing impact of the COVID-19, and he concluded that GSCM is there is an effective risk management tool that can buffer the COVID-19 adverse effects on firms. Salandri et al. (2022) studied the effect of green practices on operational performance when firms have different levels of agility and concluded that green practices, represented by green packaging, promote operational performance when firms are more agile. Wang and Li (2021) tested the effect of the institutional environment to positively regulate GSCM on firm value. Dong et al. (2021) empirically tested the differential impact of GSCM on clean technology innovation incentives of local and foreign firms from the perspective of firm identity. Xie and Zhu (2022) introduced dual knowledge search and green social capital to construct a third-order mediated adjustment model and explored the deep-rooted mechanism of the effect of GSCM practices on the relationship between green innovation and firm performance.

In summary, there is a large amount of literature in the field of GSCM research. This includes perspectives on sustainable supply chains, closed-loop supply chains and reverse logistics, GSCM and others. Among the studies on GSCM and enterprise value, some literature clearly states that GSCM can enhance enterprise value, while others are vague. Most studies use questionnaires to obtain data on enterprise GSCM and do not use micro data to analyse the relationship between GSCM and enterprise value. In some of the studies there are articles that explore the relationship between the two in depth from the perspectives of social control, institutional environment and human resources, however, we found no relevant literature examining the value enhancement of GSCM to companies from the perspective of enterprises' risk-taking level.

Therefore, the purpose of this paper is: to explore the impact of the implementation of GSCM on enterprise value, and to analyze in depth how GSCM affects enterprise value when enterprises face different levels of risk from a risk perspective. And further explores how different TIC and SCC affect the level of corporate risk-taking to influence the enhancing effect of GSCM on corporate value enhancement.

The main approach of this paper is: based on the data of 131 Chinese listed companies from 2014–2021, using panel regression, moderation and double moderation models, the role of enterprise implementation of GSCM on value enhancement is analyzed. It further analyzes how the level of risk-taking level faced by firms affects GSCM practices for corporate value when the level of risk-taking varies. It also analyzes how the implementation of GSCM by enterprises affects enterprise value when the impact of TIC and SCC on enterprise risk-taking level varies.

3 Theoretical analysis and research hypothesis

3.1 Theoretical analysis

The core idea of supply chain management theory is the collaborative operation of the supply chain, that is, how to work with suppliers, sellers, manufacturers and other subjects to achieve reasonable utilization of limited resources. The implementation of supply chain management can form a dependency relationship between different enterprises, which can promote smoother information communication and more convenient collaboration among the node enterprises in the chain, reduce the occurrence of bullwhip effect and various additional costs caused by information asymmetry (Jain, 2022), thus reducing the business risk and improving the enterprise value.

Stakeholder theory is a leading theoretical framework in sustainable economic and social development (Sajjad et al., 2020). It argues that no company can develop without the input and participation of various stakeholders (Dias et al., 2018). This coincides with the concept of supply chain management, which also emphasizes that the business situation of one enterprise in the chain is affected, and the business situation of other enterprises in the chain is also affected. Taking the core enterprise in the supply chain as an example, if the core enterprise has a stable relationship with its suppliers and sellers, it can better promote the development and economic interests of related enterprises.

Risk management theory suggests that in a risky environment, firms identify, measure and analyze risks and proactively, choose the most effective way to reduce the impact of risks on business operations. For example, financial distress and technological innovation activities carried out by firms, because the development of technological innovation activities requires continuous investment of resources (Lu et al., 2020) and the external environment is constantly changing, which is very likely to cause an increase in business risks, so under certain circumstances, operators and decision makers will suspend technological innovation activities in order to avoid risks (Wang and Rao, 2021).

3.2 Research hypothesis

3.2.1 Direct effect

Implementing GSCM by enterprises can enhance the value of enterprises. Specifically, 1) implementing GSCM can enhance the value of enterprises by reducing costs and improving resource utilization efficiency (Yildiz Çankaya and Sezen, 2018; Novitasari et al., 2022). Implementing of supply chain management affects the realization of the effective connection between supply and demand of each node enterprise in the supply chain, and the good operation of the supply chain can avoid information distortion (Neeley and Leonardi, 2018), reduce the inventory retention time (Andiappan et al., 2022), and reduce the frequency of the bullwhip effect (Xue et al., 2020), thus making more effective use of inventory resources and reducing transaction costs and inventory costs. Implementing GSCM means that the damage caused to the environment in the process of production, distribution, and even recycling is minimized (Ghobakhloo et al., 2013; Mohamed Abdul Ghani et al., 2017; Wang et al., 2020; Ali et al., 2022), which can minimize the cost of recycling and pollution reduction based on a traditional supply chain and thus enhance the value of enterprises (Karimi et al., 2021). 2) Implementing GSCM by enterprises can enhance corporate performance by improving corporate competitiveness. Meanwhile, the international community is paying increasing attention to the development of environmental protection, and various countries and regions have set green standards and requirements for import and export products. By implementing GSCM, local enterprises can integrate greening into the whole process of production and sales of goods, improve their corporate image, enhance the trust of suppliers and consumers, improve their market position and product competitiveness, and thus expand their market share and enhance their corporate value. 3) Implementing GSCM is important in promoting the green transformation of enterprises. Implementing GSCM enables enterprises to consider environmental and resource elements, coordinate the relationship between the environment and development, effectively solve increasingly serious environmental pollution and social problems, and meet the long-term interests of human development while satisfying economic development. Moreover, it is an important step that promotes the green transformation of enterprises and supports an ecological civilization and achieves the dual carbon goal (Agrawal et al., 2022). Based on the above analysis, this paper proposes the following:

H1. Implementing GSCM by enterprises can promote value enhancement.

3.2.2 Indirect effect

3.2.2.1 The moderating effect of the risk-taking level

The level of risk-taking is the ability of an enterprise to withstand the threat of potential losses in its production and business activities, reflecting the tendency of the enterprise to chase high profits and be able to pay a certain price for it. In terms of the financial crisis theory, if an enterprise only pursues high profits from projects, investments, and decisions without considering the level of risk it can bear, it undoubtedly exposes the enterprise's capital flow to great uncertainty in the process of operation and increases the possibility of financial distress (Zhou and Zhao, 2021). Therefore, the financial situation and the level of risk-taking of the enterprise influence each other. Enterprises with a low probability of financial distress will have a high level of risk-taking, at this time, they intend to make strategic decisions such as GSCM. Additionally, when an enterprise implements GSCM, it will increase the economic cost, which to some extent will increase the probability of financial distress in the enterprises and thus reduce the level of risk-taking. Therefore, enterprises will be better served to conduct GSCM for value enhancement when the risk-taking level of enterprises is high. Based on the above analysis, this paper proposes the hypothesis that:

H2. The risk-taking level has a positive moderating effect on the relationship between GSCM and enterprise value improvement. That is, in enterprises with high risk-taking ability, GSCM has a more significant impact on the improvement in enterprise value.

3.2.2.2 The impact of TIC on corporate risk-taking level

Technological innovation can inhibit the level of risk-taking. Many studies have mentioned that technological innovation is characterized by high risk and high levels of investment, which may introduce huge operational and financial risks to enterprises (Lu et al., 2020; Mao et al., 2022). Especially in the case of an uncertain external business environment and complex technological innovation, firms will avoid technological innovation as much as possible to reduce the operational risk (Wang and Rao, 2021). At the same time, technological innovation requires continuous capital injection, and the investment experiences difficulty generating good returns in the short term (Aghion et al., 2013), which can exacerbate financial distress and thus affect the level of risk-taking. Based on this, this paper proposes the following hypothesis:

H2a. TIC affects the level of corporate risk-taking and thus affects the impact of GSCM on improving corporate value. That is to say, the lower the TIC of enterprises, the smaller the probability of financial distress, which can promote the level of corporate risk-taking, thereby significantly affecting the relationship between GSCM and enterprise value.

3.2.2.3 The impact of SCC on enterprise risk-taking level

SCC can positively affect the risk-taking level of enterprises (Dai and Zhu, 2020). According to supply chain management theory and stakeholder theory, implementing supply chain management can form a dependency relationship between different enterprises, which can promote smoother communication and easier collaboration among the nodes in the chain, reduce the bullwhip effect and various additional costs caused by information asymmetry, and thus reduce the frequency of financial distress and improve the level of risk-taking. In addition, according to the supply chain stability theory and transaction cost theory, the higher SCC, the more stable the proportion of core enterprises purchasing from upstream enterprises and selling to downstream enterprises, which indicates the higher the stability of the current supply chain network, which can reduce the market cost and transaction cost of finding or developing new partners, reduce the probability of financial distress, improve the risk-taking of enterprises, and ensure the healthy operation of enterprises. Based on the above analysis, this paper proposes the hypothesis that:

H2b. SCC can affect the moderating effect of the enterprise's risk-taking level; that is, in enterprises with higher SCC, the possibility of financial distress is lower and the risk-taking level is higher, which can significantly affect the relationship between GSCM and enterprise value.

4 Research design

4.1 Model design

To examine the impact of GSCM on enterprise value, this paper constructs Model (l):

$$Q_{it} = \alpha_0 + \alpha_1 GSCM_{it} + \alpha_2 Controls_{it} + \varepsilon_{it} \qquad (1)$$

To test the moderating effect of the risk-taking level on the relationship between GSCM and enterprise value, this paper builds Model (2), which is constructed by adding moderating variables and the cross-product term of moderating variables and independent variables based on Model (1).

$$Q_{it} = \beta_0 + \beta_1 GSCM_{it} + \beta_2 RISK_{it} + \beta_3 GSCM_{it} * RISK_{it} + \beta_4 Controls_{it} + \varepsilon_{it} \quad (2)$$

In the above model, Q_{it} denotes the enterprise value of the ith firm in sample period t; $GSCM_{it}$ is the GSCM score of the ith firm in sample period t; $RISK_{it}$ is the enterprise risk-taking level of the ith firm in sample period t; controls are each control variables selected in this paper: the firm's operating year (AGE); the firm size (SIZE); equity concentration (EC); board size (BOA); degree of industry competition (LER); regional economic development (GDP) and firm (ID). In Model (1), if α_1 is positive, it indicates that implementing GSCM can promote enterprise value. Model (2), on the other hand, measures the moderating role of corporate risk-taking capacity between GSCM and value enhancement, and if β_3 is positive, it means that an increase in the risk-taking level can strengthen the role of GSCM in promoting corporate value enhancement (Jiang, 2022).

To further test the dual moderating effect of TIC and SCC on firms' risk-taking level, the dual moderating effect analysis was conducted using grouped regressions, drawing on a study by Xiao et al. (2021). Grouping the samples according to the median can avoid the regression bias caused by excessive sample size differences between the two groups. Therefore, in this paper, the samples are divided into two groups based on the median of TIC and SCC, respectively, in the double moderation effect analysis to determine the effect of an enterprise's implementation of GSCM on value enhancement when their TIC and SCC have different effects on their risk-taking level.

4.2 Variables selection

4.2.1 Explained variable

Enterprise value (Q): Financial performance is useful for directly expressing good or bad business conditions and providing security for long-term business operations, and Tobin's Q is an important indicator of a firm's market value and business performance situation (Xu et al., 2022a; Qi and Wang, 2022). Therefore, this paper chooses Tobin's Q value (Q) to characterize the firm's value. The calculation formula is: Q = market value/(total assets at the end of the period − net intangible assets − net goodwill).

4.2.2 Explanatory variable

Green supply chain management (GSCM): This paper mainly selects the CITI index in GSCM disclosed by the Center for Public Environmental Studies (IPE) to measure the GSCM score of enterprises. The CITI index is mainly a dynamic evaluation of enterprises' performance in supply chain environmental management from the perspectives of environmental compliance, energy saving and emission reduction, and information disclosure based on the information publicly disclosed by the government and enterprises. The index can objectively and systematically reflect enterprises' willingness and ability to manage environmental pollution problems of upstream and downstream manufacturers (Dong et al., 2021).

4.2.3 Moderating variables

Risk-taking level (RISK): From the perspective of corporate finance, this paper draws on the research of (Abinzano et al., 2020) and selects the Z score to measure the financial risk faced by enterprises and their ability to withstand risks. The greater the Z value is, the more stable the financial situation is and the lower the probability of financial risk.

Technological innovation capability (TIC): The proportion of R&D investment in operating income is used to measure the TIC of enterprises (Gu et al., 2018). The greater the ratio, the higher the TIC of enterprises.

Supply chain concentration (SCC): This paper uses the average of the ratio of the top five suppliers' purchases to the total annual purchases and the top five customers' sales to the total annual sales, which are disclosed in the annual reports to reflect the degree of SCC (Patatoukas, 2011; Fang et al., 2017). The higher the SCC, the better the stability of the supply chain.

4.2.4 Control variables

Company operating year (AGE): this is measured by the difference between the company's operating year and the year of establishment. In general, the longer the business time, the better the accumulation of funds, technology, credit, and other conditions, and the more conducive and capable of promoting enterprises to conduct activities. Firm size (SIZE): this selects the logarithm of the company's total assets to characterize them. Larger enterprises can optimize the efficiency of resource allocation and reduce the probability of risk (Cuerva et al., 2014). Equity concentration (EC): this is measured by the sum of the shareholding ratios of the top ten major shareholders. Board size (BOA): this is represented by the number of board members. Industry competitiveness (LER): this is the industry Lerner index used to measure the degree of competition in the industry. Regional economic development (GDP) is the GDP index of each province (last year = 100) used for measurement. Different enterprises in different provinces and local economic development impact enterprises differently. At the same time, considering that the individual differences of different enterprises may affect the regression results, this paper also controls the enterprise individual variable (ID).

4.3 Data source and processing

This paper includes data samples from enterprises and cities, specifically.

The independent variable GSCM data comes from the CITI score in the GSCM section of the IPE website, which started in 2014 and dynamically evaluates the performance of enterprises in supply chain environmental management from the perspectives of environmental compliance, energy saving and emission reduction and information disclosure with the help of publicly available information from the government and enterprises. This paper follows the sample of Chinese listed enterprises in the GSCM score disclosed by IPE from 2014–2021, and excludes the sample of financial industry, the sample of enterprises with ST and PT, the sample of enterprises listed in the current year, and the enterprises with serious missing data samples in order to avoid estimation bias as much as possible, and finally gets 131 enterprises with 316 valid observations. In order to maintain the consistency of the data sample, all other data are counted and screened based on 131 enterprises from 2014–2021.

The SCC data in the control variables were obtained from the corporate annual reports disclosed by each enterprise in the sample.

TABLE 1 Descriptive statistic.

Variables	Observation	Mean	Std	Minimum	Median	Maximum
Q	316	2.547	2.379	0.825	1.750	18.262
GSCM	316	7.529	7.985	0.000	5.250	47.880
RISK	316	3.976	5.055	−2.680	2.294	36.257
TIC	316	2.557	2.223	0.000	2.370	16.420
SCC	316	0.194	0.156	0.000	0.175	0.833
AGE	316	22.222	5.371	8.000	22.000	41.000
SIZE	316	10.202	1.449	6.897	10.173	14.477
EC	316	0.645	0.163	0.223	0.661	0.935
BOA	316	8.718	1.909	5.000	9.000	17.000
LER	316	0.165	0.117	0.028	0.128	0.511
GDP	316	1.058	0.026	0.950	1.066	1.129

The GDP data in the control variables are obtained from the statistical yearbooks of the cities where each enterprise in the study sample is located.

All other data are obtained from the China Stock Market & Accounting Research Database (CSMAR), which is a research-oriented and accurate database in the field of China's economy and finance with reference to the standards of authoritative databases such as CRSP and COMPUSTAT and is developed with the actual national conditions of China. It has covered 18 series of macroeconomics, industry economics, listed companies, stocks, funds, etc., and is widely used in existing research.

5 Finding and analysis

5.1 Descriptive statistic

Table 1 shows the descriptive statistical results of the relevant variables. The minimum value of Q is 0.825, the maximum value is 18.262, the median is 1.750, and the mean is 2.547. This means that different enterprises have great differences in operating conditions. The minimum value of GSCM is 0, the maximum value is 47.880, the median is 5.250, and the mean value is 7.529, indicating that the degree of implementation of GSCM varies among companies, and most enterprises implement GSCM to a lower degree. The minimum value of RISK is −2.680, the maximum value is 36.257, the median is 2.294, and the mean value is 3.976, indicating a large gap between whether the enterprise faces financial distress. The risk management ability of most enterprises is relatively poor, and the probability of financial distress is relatively high. The variance inflation factor test found that the mean value of the VIF is 1.11, which is far lower than the critical value of 10, indicating that the research results are not affected by multicollinearity.

5.2 Baseline regression

5.2.1 Stepwise regression

In this paper, the regression test was carried out by gradually adding variables. Table 2 reports the regression results of the impact of GSCM on enterprise value improvement. The regression results show that with the addition of variables, R^2 increases, the coefficient symbols of each variable remain unchanged, and the coefficient of the independent variable GSCM gradually stabilized at about 0.045, which means that the enterprise value increases by 0.045 percentage points for every unit increase in the score of GSCM. Hypothesis H1 is thus verified.

5.2.2 Robustness tests

Replacing variables: 1) First, we can replace the explained variable. Using the market value/total assets calculation method at the end of the period, we can replace the original calculation formula and recalculate the Tobin's Q value (QC). The regression results of Table 3 show that implementing GSCM after replacing the explanatory variables significantly improves enterprise value, assuming that H1 is established. 2) Second, we can replace the explanatory variable. Considering that the GSCM scores of different enterprises are inconsistent, this paper performs 0/1 processing on the data of GSCM based on the original data, that is, the GSCM score of i enterprise in t year is not 0, and it is assigned to 1, while the GSCM score is 0, and it is assigned to 0. The results in Table 3 show that H1 still holds after the explanatory variables are replaced.

Tailing processing: Since there may be extreme values in the original data that affect the regression results of the samples, this paper performs a 1% degree of bilateral tail reduction on the variables based on the original data. The regression results are shown in Table 3, and the conclusion is still valid.

Endogenous processing: To avoid potential endogenous problems that interfere with the regression results, this paper draws on the research of Xie et al. (2016) and selects the average level of GSCM scores of various industries and provinces where enterprises are located as instrumental variables, and conducts endogenous tests through the 2SLS method. The regression results show that the weak instrumental variable (Cragg-Donald Wald F test) significantly rejects the original hypothesis at the 5% level, and the over-identification test (Sargan test) cannot reject the original hypothesis, indicating that all instrumental variables are exogenous, and after considering the endogenous problem, implementing GSCM can still play a positive role in promoting enterprise value.

TABLE 2 Stepwise regression.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Q	Q	Q	Q	Q	Q	Q
GSCM	0.051**	0.049**	0.049**	0.045**	0.046**	0.044**	0.045**
	(2.59)	(2.47)	(2.51)	(2.29)	(2.40)	(2.28)	(2.38)
AGE		−0.032	−0.107*	−0.118**	−0.124**	−0.139**	−0.130**
		(−0.71)	(−1.82)	(−2.01)	(−2.14)	(−2.32)	(−2.24)
SIZE			0.846**	0.874**	0.845**	0.864**	0.846**
			(1.98)	(2.05)	(2.01)	(2.06)	(2.09)
EC				3.446*	3.990**	3.721*	4.318**
				(1.75)	(2.05)	(1.90)	(2.27)
BOA					−0.261***	−0.237**	−0.217**
					(−2.64)	(−2.33)	(−2.20)
LER						2.910	4.825*
						(0.99)	(1.67)
GDP							9.906***
							(3.73)
Constant	2.166***	2.902***	−4.079	−6.299	−3.970	−4.326	−15.710***
	(13.55)	(2.79)	(−1.11)	(−1.63)	(−1.02)	(−1.10)	(−3.23)
Observations	316	316	316	316	316	316	316
R-squared	0.035	0.038	0.058	0.074	0.108	0.113	0.177
ID	YES	YES	YES	YES	YES	YES	YES

Note: *, ** and *** indicate statistical significance at the levels of 10%, 5%, and 1%, respectively.

5.2.3 Heterogeneity analysis

The nature of the controlling shareholder: The decision and use of various enterprise resources are dominated by the controller (controlling shareholder). Therefore, the nature of the controlling shareholder is different, and the effect of enterprise operation and governance is also different. Based on the research of Zhang et al. (2019b), this paper divides the controlling shareholders into state-owned controlling shareholders (SOCS) and non-state-owned controlling shareholders (NSOCS) and analyzes the promotion effect of GSCM on enterprise value in enterprises with different controlling shareholders. The test results are shown in Table 4. It can be seen from Table 4 that for the enterprises of NSOCS, the coefficient of GSCM is significant at the 5% level, which means that GSCM can promote the value of the enterprise under the influence of NSOCS. On the other hand, the coefficient of GSCM of SOCS is insignificant, indicating that the impact of GSCM on the value of enterprises of SOCS is not obvious. The possible reasons for this are that enterprises influenced by SOCS are more likely to have unclear ownership, poor self-motivation, etc., resulting in the absence of managers, inefficient management and governance, etc., and affecting business and governance. When the business of enterprises of NSOCS is in good condition, shareholders can obtain greater vested interests and further lay a good foundation for realizing self-worth. Therefore, compared with SOCS, NSOCS can better play their leading role, promote enterprises to conduct GSCM, and promote enterprise value.

Type of enterprise: Different types of enterprises face different development conditions on the background of economic structure transformation and the dual carbon strategy. 1) Polluting-intensive enterprises (PIE) and non-polluting-intensive enterprises (NPIE). PIE face more severe transformation goals and policy regulations in the current context. According to the research of Liu and Liu (2015), enterprises with industry codes C19, C22, C26, C29, C30, C31, and D44 in the sample are defined as PIE, and enterprises in other industries are defined as NPIE. The results of the heterogeneity analysis are shown in Table 4. The results show that the coefficient of GSCM of NPIE is significant at the 5% level, which means that GSCM can promote the value of NPIE. The coefficient of GSCM of PIE is insignificant, indicating that implementing GSCM has no obvious impact on the value improvement in PIE. The possible reason for this is that PIE have a certain particularity in that implementing green processes costs more. At the same time, implementing of GSCM is not only the implementation of PIE, but also needs the implementation of other enterprises. However, the operators of other enterprises think that improving the environment and implementing greenization is the responsibility of PIE, and this sentiment reduces the sensitivity of enterprises on the chain to

TABLE 3 Robustness tests.

Variables		Replacing the explained variable	Replacing the explanatory variable	Tailing processing	Endogenous processing
GSCM		0.038**		0.040**	0.070***
		(2.15)		(2.34)	(3.36)
gscm			1.044***		
			(3.15)		
AGE		−0.131**	−0.205***	−0.131**	−0.120***
		(−2.40)	(−3.44)	(−2.46)	(−2.72)
SIZE		0.992**	0.971**	0.756**	0.846***
		(2.59)	(2.41)	(2.01)	(2.77)
EC		3.198*	4.345**	4.215**	4.046***
		(1.78)	(2.32)	(2.37)	(2.80)
BOA		−0.165*	−0.216**	−0.106	−0.224***
		(−1.77)	(−2.22)	(−1.14)	(−3.01)
LER		4.252	4.525	5.675**	4.395**
		(1.56)	(1.59)	(2.16)	(2.01)
GDP		9.317***	10.710***	10.625***	9.923***
		(3.72)	(4.06)	(4.07)	(4.95)
Constant		−16.429***	−16.779***	−16.587***	−20.379***
		(−3.58)	(−3.48)	(−3.60)	(−4.44)
Observations		316	316	316	316
R-squared		0.164	0.196	0.182	0.891
ID		YES	YES	YES	YES
Cragg-Donald Wald F					74.597**
Sargan					1.351

*, ** and *** indicate statistical significance at the levels of 10%, 5%, and 1%, respectively.

implementing GSCM. 2) Technology-intensive enterprises (TIE) and non-technology-intensive enterprises (NTIE). According to the CSRC's 2012 industry classification standard, firms with industry codes C27, C34, C35, C36, C37, C38, C39, and M74 are defined as TIE, and the rests are NTIE. The regression results of Table 4 show that the coefficient of GSCM of NTIE is significant at the 1% level, which means that GSCM can promote the value of enterprises of NTIE. The GSCM coefficient of TIE is insignificant, indicating that implementing GSCM has no obvious impact on the value improvement in TIE. The possible reasons for this are as follows: compared with TIE, NTIE have poor technical capabilities, and the green and sustainable development of supply chain management requires enterprises to have certain technical capabilities and conditions. At the same time, digital technology has played a greater role during the COVID-19 epidemic. Therefore, implementing GSCM in enterprises with poor technical ability will help them improve their technical level and promote their ability to transform technological and other capabilities into value improvement. Therefore, implementing GSCM in NTIE will play a more significant role in promoting enterprise value.

5.3 Further analysis

5.3.1 The moderating effect test of enterprise risk-taking level

The regression results in Table 5 show that the interaction term coefficient between GSCM and corporate risk-taking is 0.013 and significant at the 1% level, indicating that when the risk-taking level is higher, implementing GSCM can better promote an improvement in corporate value. It is not difficult to understand that, as mentioned earlier, the implementation of GSCM by enterprises will reduce the risk-taking level of enterprises and increase the possibility of enterprises facing financial difficulties. Only when the enterprise's risk-taking level is higher, it can show that the enterprise does not have the possibility of facing higher financial distress under the current business condition, and the enterprise will have the intention to

TABLE 4 Heterogeneity analysis.

Variables	State-owned controlling shareholders	Non-state-owned controlling shareholders	Polluting-intensive enterprises	Non-polluting-intensive enterprises	Technology-intensive enterprises	Non-technology-intensive enterprises
GSCM	0.015	0.050**	0.000	0.044**	−0.016	0.081***
	(0.77)	(2.39)	(0.00)	(2.22)	(−1.15)	(2.95)
AGE	0.451**	−0.126*	0.049	−0.164**	−0.083	−0.093
	(3.16)	(−1.89)	(0.37)	(−2.39)	(−1.10)	(−1.29)
SIZE	−5.449***	0.893*	1.029	1.073**	0.435	0.958*
	(−4.34)	(1.95)	(0.91)	(2.30)	(0.89)	(1.91)
EC	0.656	4.203**	−5.608	5.943***	2.454	5.448**
	(0.17)	(2.02)	(−1.01)	(2.74)	(1.28)	(2.27)
BOA	0.018	−0.260**	0.469	−0.248**	0.071	−0.332**
	(0.31)	(−2.21)	(0.80)	(−2.44)	(1.16)	(−2.26)
LER	−17.363**	4.919	9.826	6.014*	3.286	4.572
	(−2.43)	(1.45)	(1.61)	(1.78)	(0.70)	(1.30)
GDP	−0.581	10.175***	10.514	10.058***	3.715**	11.851***
	(−0.25)	(3.33)	(1.58)	(3.39)	(2.05)	(3.15)
Constant	51.772***	−16.005***	−21.403*	−18.539***	−7.415	−19.212***
	(3.52)	(-2.93)	(−1.93)	(−3.23)	(−1.50)	(−3.03)
Observations	35	281	48	268	102	214
R-squared	0.870	0.185	0.259	0.202	0.160	0.236
ID	YES	YES	YES	YES	YES	YES

*, ** and *** indicate statistical significance at the levels of 10%, 5%, and 1%, respectively.

implement GSCM. Therefore, the higher the risk-taking level of the enterprise, the more it can indicate that the current enterprise does not have financial distress, and the more it can support the enterprise to carry out GSCM. That is, when the enterprise risk-taking level is higher, the positive promotion effect of implementing GSCM on enterprise value enhancement is obvious.

5.3.2 Test on the dual moderating effect of TIC and SCC

The regression results of the dual moderating effects of Table 5 show the following: 1) When the TIC of enterprises is low, the moderating effect of the risk-taking level is more significant. This is because enterprises conducting technological innovation work spend a lot of manpower and material resources, which increases the probability of corporate financial difficulties and financial constraints, debt risk, etc., and implementing GSCM also requires enterprises to continuously inject funds; when the financial risks faced by enterprises are too large, it is not conducive for enterprises to conduct GSCM. Therefore, the lower the TIC of enterprises, the more significant the role of the risk-taking level in promoting enterprise value using GSCM. Hypothesis H2a thus holds. 2) When the SCC is higher, the risk-taking level plays a more significant role in implementing GSCM to promote enterprise value. SCC is measured by the average of the sum of the proportion of the top five customers and suppliers in the overall sales and procurement. The higher the SCC value, the stronger the relationship between enterprises, and the more conducive it is for enterprises to establish a stable supply and sales network and reduce procurement and sales risks and costs to increase the abundance of funds to conduct GSCM and turn it into enterprise value. Therefore, the higher the SCC value, the more significant the role of the risk-taking level in GSCM promoting enterprise value. Hypothesis H2b thus holds.

6 Discussion and conclusion

6.1 Discussion

In the existing research, most articles analyze how GSCM improves corporate value, but analyzing mechanisms and paths and discussing the relationship between the two is not comprehensive. The implementation of GSCM requires enterprises to inject funds continuously, and enterprises' financial level reflects the enterprises' risk-taking ability to a certain extent. At the same time, the risk-taking level of enterprises is affected by the degree of technological innovation and the stability of the supply and sales network. Therefore, this paper first examines the impact of GSCM on enterprise value and analyzes the regulatory role of the risk-taking level in promoting enterprise value by GSCM, further discussing the dual-level regulatory role of TIC and SCC. The innovation of this paper lies in. 1) Enriching the research on the impact of GSCM on enterprise value. 2) From the perspective of corporate risk-taking level, this paper studies the role of the risk-taking level in GSCM to enhance enterprise value. 3) This paper further

TABLE 5 Moderating effect analysis.

Variables	Regulation of risk-taking levels	Higher technological innovation capability group	Lower technological innovation capability group	Higher supply chain concentration group	Lower supply chain concentration group
GSCM	0.005	−0.012	−0.018	0.021	−0.024
	(0.23)	(−0.53)	(−0.46)	(0.48)	(−0.71)
RISK	0.039	0.181***	−0.117	−0.140*	0.205**
	(0.85)	(2.74)	(−1.32)	(−1.82)	(2.40)
GSCM*RISK	0.013***	0.007	0.023**	0.022***	0.011
	(2.99)	(1.58)	(2.51)	(2.80)	(1.18)
AGE	−0.126**	−0.081	−0.038	−0.132	−0.114*
	(−2.26)	(−0.89)	(−0.46)	(−1.06)	(−1.71)
SIZE	0.830**	0.344	1.261*	1.280*	1.730***
	(2.13)	(0.52)	(1.92)	(1.69)	(2.90)
EC	4.073**	6.610**	4.273	3.137	0.325
	(2.20)	(2.59)	(1.38)	(0.78)	(0.14)
BOA	−0.198**	0.004	−0.575***	−0.502***	0.098
	(−2.11)	(0.04)	(−3.18)	(−2.98)	(0.94)
LER	4.407	2.834	2.595	10.296	3.282
	(1.60)	(0.63)	(0.74)	(1.51)	(1.29)
GDP	10.461***	7.851***	10.430**	12.586***	11.794***
	(4.09)	(2.94)	(2.60)	(2.76)	(3.91)
Constant	−16.323***	−13.201**	−18.265**	−19.971**	−28.143***
	(−3.42)	(−2.07)	(−2.25)	(−2.16)	(−3.86)
Observations	316	158	158	158	158
R-squared	0.260	0.371	0.333	0.419	0.343
ID	YES	YES	YES	YES	YES

*, ** and *** indicate statistical significance at the levels of 10%, 5%, and 1%, respectively.

explores how the level of risk-taking affects the role of GSCM in promoting enterprise value when the TIC and SCC adjust the level of risk-taking.

6.2 Conclusion

This paper uses the data of 131 Chinese listed companies from 2014 to 2021 to empirically test the impact of implementing GSCM on improving enterprise value. At the same time, to clarify the path of implementing GSCM affecting the improvement in enterprise value, this paper also explores the regulatory role of the risk-taking level, further analyzes the dual regulatory role of TIC and SCC and draws the following conclusion. 1) Enterprises carrying out GSCM can promote an improvement in enterprise value. 2) The nature of the controlling shareholders of enterprises is different, the type of enterprise is different, and the role of GSCM in enhancing corporate value is different. When the enterprise is NSOCS, NPIE and NTIE types, implementing GSCM significantly promotes enterprise value. 3) The level of corporate risk-taking can positively regulate the role of GSCM in enhancing enterprise value; that is, the higher the level of risk-taking, the more GSCM can promote enterprise value. 4) The level of corporate risk-taking is moderated by TIC and SCC. When the TIC is low or the SCC is high, the level of risk-taking plays a more significant role in promoting corporate value *via* GSCM.

7 Practical enlightenment

Implementing GSCM can promote an improvement in enterprise value. To achieve this goal, we should focus on the following.

(1) Starting from the government, through guidance, encouragement, and other measures to promote GSCM—we should cultivate new economic growth points and promote the acceleration of the green, intelligent, and high-end transformation and upgrading of traditional industries to form new competitive advantages and

thus realize the win–win situation of ecological protection and promote the greening of enterprises. The research results reveal that when enterprises have a good level of risk-taking, the role of the GSCM in promoting enterprise value is more obvious. In addition, improving the enterprise's TIC is not conducive to the enterprise's risk-taking level, but implementing greenization and ecologicalization will inevitably require an injection of capital, technological, and other costs. This requires government departments to issue special support policies to strengthen support for enterprises with good finances and talent; at the same time, market resources must be guided to achieve rational allocation and ensure an improvement in the TIC of enterprises and the stability of capital and cash flow.

(2) Starting from enterprises, we should deepen the management and operation awareness of the coexistence of ecological protection and economic benefits, actively incorporate greening and sustainability into the scope of enterprise management and supply chain collaboration and internalize the cognition and practice of GSCM in the ideological culture and operation management. The different types of shareholders and the different types of enterprises will affect the implementation of GSCM. This requires enterprises to adjust measures to local conditions when implementing GSCM and not blindly follow the trend so as not to cause greater management and operational risks. The higher the SCC, the better the moderating effect of the risk-taking level. On the one hand, the higher the SCC, the better the supply chain network's stability. At this time, enterprises can implement the concept of environmental protection in the process of product manufacturing and sales using cooperation and interaction with upstream and downstream enterprises to enhance the overall greening of the chain and enhance enterprise value and performance. On the other hand, the better the stability of the supply chain, the better the positive regulatory effect of the risk-taking level is. At this time, different enterprises can establish the concept and channel of cooperation and strive to build a mutually beneficial supply and sales system. Product manufacturing and raw material supply enterprises can continuously improve their product quality, and commodity sales enterprises can improve their sales methods. While improving their competitiveness, they can increase the demand and support of other enterprises for their own enterprises, improve the stability of supply and sales networks, and reduce the probability of financial risks to improve their performance when implementing GSCM.

8 Research limitations and future research directions

This paper has found that the level of risk-taking can positively promote the role of GSCM in terms of enterprise value enhancement, and TIC and SCC also influence the level of risk-taking, but there are certain shortcomings.

Firstly, due to data limitations, the CITI index disclosed by IPE is selected to measure the GSCM level of companies in this paper, but the index only evaluates some specific companies, and the overall sample size is small. Future research could: 1) A universal evaluation index system can be constructed based on the evaluation criteria of IPE to meet the purpose of evaluating the GSCM scores of all companies. 2) Further, the statistical method can be used to argue the role of GSCM implementation on enterprise value based on the evaluation scores, so that the research conclusions can be more convincing to promote and facilitate the implementation of GSCM in enterprises.

Secondly, the benefits of implementing GSCM for enterprises are not only reflected in value enhancement, but future research can also analyze the benefits brought by the implementation of GSCM for enterprises from the perspective of enterprise competitiveness, inventory cost, and green development.

Finally, the lack of other regulating factors in the theoretical analysis and research process, future research could also find, study and argue how the implementation of GSCM affects enterprise value enhancement from the perspective of customers and suppliers, to enrich the research of GSCM and promote the implementation of GSCM in enterprises, to achieve a win-win situation of economic benefits and environmental protection.

Data availability statement

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

Author contributions

Conceptualization, LZ and YD; methodology, LZ and YD; software, LZ and YD; validation, LZ; formal analysis, LZ and YD; resources, LZ and YD; data curation, LZ and YD; writing—original draft preparation, LZ and YD; writing—review and editing, LZ, YD, and HW; visualization, LZ and YD; supervision, LZ, YD, and HW; project administration, YD and HW; funding acquisition, YD and HW. All authors have read and agreed to the published version of the manuscript.

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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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Foreign experience of CEO and corporate social responsibility: Evidence from China

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Foreign experience is a mechanism through which personal cognitions can be shaped into idiosyncratic characteristics. Under the unique institutional background of China, the purpose of this paper is to examine whether CEOs' foreign experience will affect the performance of CSR and whether the influences of CEOs' foreign experience on CSR vary from the categories of foreign experience or from the governance environments. We find that firms with returnee CEOs show better CSR performance. Moreover, the longer the CEO's foreign experience, the better is the CSR performance. Our results are robust to endogeneity concerns, inclusion of additional control, and alternative measures of key variables. Further analyses indicate that foreign working and integrated experiences have important impacts on CSR performance; and the positive effect of foreign experience on CSR is more pronounced for firms located in better legal environment and for those audited by reputable auditor. Our findings highlight foreign experience of CEO as an important driver of CSR performance.

KEYWORDS

CEOs' foreign experience, corporate social responsibility, cognition, upper echelons theory, brain gain

1 Introduction

Corporate social responsibility (CSR) refers to the managerial responsibility that a firm should take for the welfare of stakeholders in their business operations. The concept of CSR is based on the idea of sustainable development. In addition to financial objectives, corporate business operations must be aligned with social development and environmental concerns (McWilliams and Siegel, 2001; Ali et al., 2022a). As Carroll (1979) states, CSR includes economic, ethical, legal, and communal expectations that society has of organizations. By integrating social and environmental requirements into long-term corporate strategies, firms that engage in CSR activities are preferred in the capital market and under severe industry competition (Ferrell et al., 2016; Liang and Renneboog, 2017; Chen J. et al., 2020). Accordingly, CSR has received considerable attention from scholars and practitioners, especially since the recent global environmental issues, resource scarcity, increased unemployment, and financial scandals (García and Sanz, 2018; Gonçalves et al., 2020).

Our paper builds on two streams of previous literature. The first is research on the determinants of CSR performance. In order to achieve sustainable development, firms have incentives to fulfill their social responsibilities. Prior studies document several factors that affect performance of CSR including external environments (Adnan et al., 2018; Ali et al., 2019; Ucar and Staer, 2020), institutional investors (Dyck et al., 2019; Nofsinger et al., 2019; Chen T. et al., 2020), media attention (Byun and Oh, 2018), ownership structure (Ali et al., 2019; Chen and Cheng, 2020; Chi et al., 2020), board characteristics (Cho et al., 2017;

Muttakin et al., 2018), and managerial characteristics (Hegde and Mishra, 2019; Chen J. et al., 2020; Ali et al., 2022b).

Another stream of research is on the economic consequences of hiring returnee talents. In recent years, economic globalization and convenient transportation have promoted the international flow of talents (Wen et al., 2020). Previous studies indicate that managerial heterogeneity stemming from foreign experience impacts on corporate governance (Giannetti et al., 2015; Iliev and Roth, 2018), corporate performance (Estélyi and Nisar, 2016; Le and Kroll, 2017), and corporate decision-makings, like innovation (Yuan and Wen, 2018), tax avoidance (Wen et al., 2020), CEO compensation (Conyon et al., 2019), and earnings management (Du et al., 2017).

Overall, a large body of previous studies examine both internal governance mechanisms and external institutional factors affecting CSR performance. Meanwhile, prior literature have long been exploring economic consequences of managerial characteristics. Notwithstanding, the impact of managerial foreign experience on CSR is still an issue that needs empirical test. Our study aims to fill the research gap by introducing two essential issues: (1) Does a CEO's foreign experience improve the firm's performance of CSR; (2) Are there heterogeneous influences of a CEO's foreign experience on CSR for different categories of foreign experience or for different governance environments.

The unique institutional background of China provides us the appropriate environment for examination. Compared with developed countries where CEOs have gained foreign experience, China lacks the perfection of institutions and capital markets (Peng and Zhou, 2005), offering a different institutional environment to investigate the impact of CEOs' foreign experience on Chinese corporate behaviors. Meanwhile, China is at the stage of transformation from high-speed development to high-quality development. Talent is a strategic driving force for Chinese economy. However, talent with foreign experience is still scarce in the Chinese labor market despite the economic development and the implementation of brain gain policies (Giannetti et al., 2015; Yuan and Wen, 2018). The supply of talent with foreign experience cannot fully meet the needs of all Chinese enterprises, leading to heterogeneity between regions and companies regarding the recruitment of returnee senior executives.

To test the impact of CEOs' foreign experience on CSR performance, we manually collect data of CEOs' foreign experience from corporate annual reports and related internet websites. The important aspects of CEOs' foreign experience include the duration, category and the host country or region of foreign experience. Further, our paper employs two variables as the proxy for CEOs' foreign experience. One is a dummy variable indicating whether a CEO had foreign experience. The other is a continuous variable measuring the duration of a CEO's foreign experience. As for the performance of CSR, we use RKS's CSR ratings that is widely used in related previous studies. To control for the unobservable firm-specific heterogeneity, firm-fixed effects models are adopted for evaluations. Consistent with our predictions, our study finds that a CEO's foreign experience significantly improves the CSR performance. Moreover, there is a positive and significant relationship between the duration of a CEO's foreign experience and the performance of CSR. We conduct a series of analytical tests to verify the robustness of the results. Additionally, the positive impact of foreign experience on CSR is mainly derived from foreign working and integrated experiences rather than foreign educational experience. The effect of a CEO's foreign experience on CSR is strengthened by legally protective environments and high-quality external auditing.

Our research makes the following contributions to existing literature. First, we supplement the growing literature on the determinants of CSR by presenting the significant effect of CEOs' foreign experience on the performance of CSR. Previous studies demonstrate the role of corporate external and internal factors on facilitating CSR performance. However, little is known about how foreign experience of CEOs drives CSR practices. Our analysis provides the theoretical frameworks and empirical evidence to address the above issue. Second, our results highlight the importance of hiring and retaining senior executives with foreign experience capable of improving the performance of CSR and enabling firms to acquire a better social reputation. Therefore, our paper expands the stream of study on the economic consequence of senior executives' early experiences. Finally, given the increased importance of talent and the development of talent markets, Chinese central and provincial governments recently implemented a series of preferential policies to introduce overseas talent. By exploring the influence of CEOs' foreign experience on corporate social behaviors, our study provides firm-level empirical evidence on the validity of China's brain gain policies.

The remainder of the paper is organized as follows. Section 2 discusses the related theory and develops testable hypotheses. Section 3 describes our research design including the sample selection, data, measures of key variables, and applied regression models. Empirical results are presented in Section 4. To examine the validity of our results, we conduct several robustness tests in Section 5. Further analyses for the heterogeneous effects of foreign experience on CSR are discussed in Section 6. Section 7 presents the conclusion of the paper.

2 Theory and hypotheses

Since Hambrick and Mason (1984) put forward the upper echelons theory, the literature regarding the relationship between senior executives and corporate behaviors has gradually attracted attention. According to the upper echelons theory, it is difficult for senior executives to fully understand all the information related to enterprise decision-making due to the cognitive limitations of senior executives and uncertainties of corporate environments. The existing cognitive structure of senior executives impacts their understanding of relevant information, affecting corporate decision-making. The characteristics of senior executives play an important role in forming their cognitive structure. Existing literature investigates the effects of senior executives' gender (Khaw et al., 2016; Adhikari et al., 2019; Luo et al., 2020), age (Paul and Shrivatava, 2016; Kunze and Menges, 2017; Li et al., 2017; Zhu et al., 2021), family status (Zellweger et al., 2013; Hegde and Mishra, 2019; Vandekerkhof et al., 2019), foreign background (Giannetti et al., 2015; Fu et al., 2017; Yuan and Wen, 2018; Conyon et al., 2019; Wen et al., 2020), educational background (King et al., 2016; Wang and Yin, 2018; Mun et al., 2020), ability

(Mishra, 2014; Jung and Subramanian, 2017; Uygur, 2018), and other characteristics (Custódio and Metzger, 2014; Beneish et al., 2017; Cheung et al., 2017; Sunder et al., 2017) on corporate activities and decision-making.

Given that CSR activities reflect managerial behaviors that improve the welfare of customs, employee, environment, society and other stakeholders, beyond the interests of shareholders or without legal requirements (McWilliams and Siegel, 2001), senior executives have discretions in the engagement of CSR activities. Based on the concept of upper echelons theory, managerial cognitive structure impacts on such discretionary decisions and therefore exerts a crucial influence on the establishment of CSR strategy (Petrenko et al., 2016).

As a comparison of prior literature examining the effects of executive psychological features and personal values, for instance, narcissism (Petrenko et al., 2016; Al-Shammari et al., 2019), hubris (Tang et al., 2015; Tang et al., 2018) and political ideologies (Chin et al., 2013), on CSR practices, we focus on CEOs' foreign experience as a determinant of CSR performance. As the executive leader of corporate top management teams, CEOs' foreign experience molds their unique cognitive structure, affects their identification and judgment of useful information for decision-making. Thus, it plays an important role in corporate performance or strategic choice. Bhagwati and Hamada (1974) propose that well-educated labor force and professionals from developing countries tend to flow to developed countries. Yuan and Wen (2018) believe that CEOs from developing countries are more likely to choose developed countries to complete their foreign experience. In this vein, we posit that a CEO's foreign experience obtained from developed countries can affect the performance of CSR in the following ways.

First, CEOs with foreign experience generally acquire high-quality knowledge or skill training, laying a solid professional foundation and accumulating rich management experience for their follow-up domestic work. Compared with local CEOs without foreign experience, returnee CEOs tend to have a stronger ability to identify and process key information, and more skillfully recognize the corporate status and developmental trends. Besides, foreign experience leads CEOs to a confrontation with different systems of value or with different institutions, which furthers CEOs to have a global mindset and therefore to more consider stakeholders. When stakeholders have higher requirements on the performance of CSR, CEOs with foreign experience have a deeper understanding of the demands of stakeholders, thereby promoting CSR performance.

Additionally, with the development of capital markets in developed countries, publicity and education related to CSR have been established, and corresponding legal systems or national strategies have been promulgated. During their stay in developed countries, for work or education, CEOs obtain the cognition on fulfillment of CSR and comprehend its positive consequences on firms. Therefore, foreign experience in developed countries enhances the importance of CSR in a CEO's cognition and makes corporate strategies stakeholder-orientated. Compared with the relatively sound CSR environments in developed countries (Campbell, 2007), Chinese firms generally have low awareness of social responsibility (Yin and Zhang, 2012). Therefore, foreign experience helps CEOs acknowledge the concept of CSR and significantly enhance CSR fulfillment after their return to China.

Meanwhile, while working or studying abroad, CEOs understand the normalization and authority of contracts in foreign markets and the serious litigation risks and reputation-destroying costs incurred by violating contracts or damaging stakeholders' interests. The favorable legal and regulatory environment in developed countries makes CEOs with a foreign experience more cautious and risk-averse (Yuan and Wen, 2018). This trait continues to affect even after CEOs have returned to their homeland. Prior studies indicate that returnee senior executives can implement more effective corporate governance and risk control mechanisms (Giannetti et al., 2015; Yuan and Wen, 2018). Predictably, CEOs with foreign experience are more willing to fulfill CSR activities for the sake of protecting stakeholders' legitimate rights and proactively avoiding risks caused by the lack of CSR engagements.

Finally, compared with the relatively laggard CSR management practices of Chinese enterprises, firms in developed countries have rich experience fulfilling CSR. While working or studying abroad, CEOs familiarize themselves with management practices and understand advanced operation modes of foreign enterprises. Importantly, CEOs would have more opportunity to participate in the fulfilling of CSR in foreign enterprises. Upon their return to China, CEOs can apply relevant experiences to management activities and improve the CSR performance of Chinese enterprises. Therefore, we develop the following baseline hypothesis.

Hypothesis 1: Firms that have CEOs with foreign experience will show greater CSR performance than firms that have CEOs without foreign experience.

To further examine the effect of CEOs' foreign experiences, we investigate how the duration of a CEO's foreign experience affects a firm's CSR performance, to provide additional evidence for the relationship between CEOs' foreign experience and CSR. Based on the upper echelons theory, CEOs' characteristics formed by their past experiences can explain the variances in corporate behaviors. Foreign experience can strengthen CEOs' ability to identify and process key information, recognize the concept of CSR, avoid the risk of lack of CSR, and enrich their experience of CSR engagement. Moreover, the acquisition of foreign experience is a process by which CEOs continuously adapt to different institutional environments and gradually realize that effective institutions have significant governance effects on firms' behaviors. Importantly, the longer the process lasts, the greater the impact of the characteristics shaped by foreign experiences on CEOs' subsequent career and decision-making. Therefore, with the increase in CEOs' foreign experience, the influence of foreign institutional environments is gradually more profound, strengthening the positive impact on CSR performance. Accordingly, we propose the following hypothesis.

Hypothesis 2: The longer the CEOs' foreign experience, the better the CSR performance of the Chinese firms they serve.

3 Research design

3.1 Sample selection and data

Our sample companies were chosen from Chinese firms listed on the Shanghai Stock Exchange and Shenzhen Stock Exchange between 2011 and 2014. We end the sample at 2014 because Ministry of Finance of China revised or added a number of accounting standards in 2014,

TABLE 1 Definitions of variables.

Variables	Definitions
Dependent variables	
RKS_CSR	Natural logarithm of a firm's CSR score disclosed by the RKS
RKS_GAD	Firm's CSR grade disclosed by the RKS. Each firm-year is graded from AAA + to C (19 grades in total) based on its *RKS_CSR*. We assign a value of 19 (1) to AAA+ (C) grade indicating the highest (lowest) quality of CSR
HEXUN_CSR	Natural logarithm of a firm's CSR score disclosed by the Hexun.com
Independent variables	
CEOFE_D	A dummy variable that takes a value of one if the CEO has foreign working or educational experience, and zero otherwise
CEOFE_L	Natural logarithm of one plus the duration (number of years) of CEOs' foreign experience
Instrument variables	
EDU3	Score of the Chinese universities from which CEOs obtained their bachelor's degree. A score of 3 is assigned to the universities if their percentile of the average national entrance exam score of incoming freshmen students is between 90 and 100, a score of 2 is assigned to the universities if their entrance percentile score is between 80 and 90, and a score of 1 is assigned to the universities if their entrance percentile score is below 80. If the company does not disclose the Chinese university the CEO attended, we assign a score of 1 Giannetti et al. (2015)
EDU4	Score of the Chinese university from which the CEO obtained a bachelor's degree. Equals to *EDU3*, except for cases that we assign a score of 0 if the company does not disclose the Chinese university the CEO attended Giannetti et al. (2015)
AGE	CEO's age is the difference between the current year and the birth year
CEOFE_DIY	Industry-year average of *CEOFE_D*
CEOFE_LIY	Industry-year average of *CEOFE_L*
Country-level institutional variables	
LAW	Rule of Law index of the country or region where CEOs obtained their foreign experience (Source: Worldwide Governance Indicators from the World Bank)
CORRUPT	Control of Corruption index of the country or region where CEOs obtained their foreign experience (Source: Worldwide Governance Indicators from the World Bank)
REVISED	Revised Anti-director index of the country or region where CEOs obtained their foreign experience (Source: Djankov et al., 2008)
ORIGIN	A dummy variable equals to one if CEOs obtained their foreign experience from the country or region which belongs to English Law origin, and zero otherwise (Source: Djankov et al., 2008)
Moderating variables	
LEI	Market and legal environment index from Wang et al. (2017)
BIG4	A dummy variable that takes a value of one if the firm-year is audited by one of international Big 4 auditors, including Deloitte, Ernst and Young, KPMG, and PricewaterhouseCoopers, and zero otherwise
Control variables	
SIZE	Natural logarithm of the total assets
ROA	Return of assets
MTB	Market-to-book ratio is the sum of the book value of total liabilities and the market value of equity, divided by the book value of total assets
LEV	Firm leverage equals to the ratio of total liability to total assets
OCF	Operating cash flow divided by total assets
PPE	Property, plant, and equipment divided by total assets
BLOCK	Percentage of shares owned by the largest shareholder
RESTRAIN	Percentage of shares owned by the largest shareholder divided by the percentage of shares owned by the second-largest shareholder
BOARD	Natural logarithm of the number of board members
ID	Proportion of independent directors over total board members
DUAL	A dummy variable that takes a value of one if the CEO also serves as chairperson of the board
STATE	A dummy variable that takes a value of one for state-owned enterprises and zero for others
DIRFE	A dummy variable that takes a value of one if at least one director on-board has foreign experience, and zero otherwise

which will affect the comparability of financial reports of listed companies in the following years. The CSR data is obtained from CSR Ratings of Rankins (hereafter denoted as RKS). Based on the resumes of CEOs disclosed in corporate annual reports and Sina finance (finance.sina.com.cn) as a complementary information source, we manually collected data regarding the foreign experience of CEOs, including the duration, category and the country or region of foreign experience. Corporate financial and governance data are separately obtained from the China Stock Market and Accounting Research (CSMAR) and the China Center for Economic Research (CCER) databases. The data on the regional legal environment of the sample firms are taken from the marketization index of Chinese provinces published by Wang et al. (2017). The country-level data of institutional characteristics of CEOs' foreign experience are obtained from Worldwide Governance Indicators compiled by the World Bank and from Djankov et al. (2008).

Financial companies are excluded from our sample due to their unique regulatory environments and different financial statement

TABLE 2 Summary statistics.

Panel A: Descriptive analysis						
Variables	N	Mean	S.D.	25% percentile	Median	75% percentile
RKS_CSR	2,165	3.5655	0.2976	3.3711	3.5261	3.7259
CEOFE_D	2,165	0.0374	0.1898	0.0000	0.0000	0.0000
CEOFE_L	81	1.3828	0.4702	1.0986	1.0986	1.6094
SIZE	2,165	22.9166	1.3679	21.9183	22.8271	23.8871
ROA	2,165	0.0421	0.0533	0.0148	0.0367	0.0664
MTB	2,165	1.8390	1.1165	1.1260	1.4817	2.1175
LEV	2,165	0.5003	0.2072	0.3474	0.5184	0.6625
OCF	2,165	0.0454	0.0699	0.0064	0.0453	0.0874
PPE	2,165	0.2523	0.1868	0.1017	0.2084	0.3785
BLOCK	2,165	39.2943	16.3047	25.5100	39.6200	51.3200
RESTRAIN	2,165	16.6842	32.8824	2.0358	5.2596	17.3808
BOARD	2,165	2.2451	0.2378	2.1972	2.1972	2.3979
ID	2,165	0.3726	0.0751	0.3333	0.3636	0.4167
DUAL	2,165	0.1612	0.3678	0.0000	0.0000	0.0000
STATE	2,165	0.6379	0.4807	0.0000	1.0000	1.0000
Panel B: Mean difference tests of *RKS_CSR* base on *CEOFE_D*						
Mean of *RKS_CSR*	*CEOFE_D* = 0 3.5952 (N = 2084)		*CEOFE_D* = 1 3.5773 (N = 81)		Difference 0.0179	*t-stat* 0.4899
Panel C: Mean difference tests of *RKS_CSR* base on *CEOFE_L*						
Mean of *RKS_CSR*	*CEOFE_L* < its mean 3.5377 (N = 52)		*CEOFE_L* ≥ its mean 3.6483 (N = 29)		Difference −0.1106	*t-stat* −1.4993*

formats (Vafeas, 2000; Peasnell et al., 2005; Firth et al., 2007). We excluded firms for which necessary data was not available. Noteworthily, not all listed companies are included in RKS's CSR ratings database since social responsibility reports are not compulsorily required by China securities regulatory commission. Finally, 2,165 firm-year observations (involving 674 firms) are adopted. To mitigate the bias from outliers, we winsorized all continuous variables at the 1st and 99th percentiles.

3.2 Variables

3.2.1 Corporate social responsibility

Following previous studies (Lau et al., 2016; Liao et al., 2018; Luo and Liu, 2020; Kong et al., 2021), we adopt RKS's CSR ratings as the proxy for CSR (*RKS_CSR*). RKS is an authoritative third-party rating agency for CSR in China, committed to providing reliable, time-series and firm-level information regarding CSR ratings for corporate investors, consumers, and the public. RKS's CSR ratings are weighed estimated by four dimensions of CSR quality, including macrocosm (30%), content (45%), technique (15%), and industry (10%). Specifically, macrocosm refers to the strategy on CSR, content focuses on the implementation of CSR, technique represents the information disclosure of CSR and industry involves the industry-specific criteria for rating CSR engagement (Zhang et al., 2018). High value of RKS's CSR ratings (*RKS_CSR*) indicates high quality of CSR. To verify robustness, we use the CSR scores from Hexun.com covering corporate responsibility for shareholders, employees, suppliers/customers/consumers, environments and society, as an alternative proxy for CSR.

3.2.2 CEO's foreign experience

We measure CEOs' foreign experience by whether they have foreign experience (*CEOFE_D*) and by the duration of their foreign experience (*CEOFE_L*). *CEOFE_D* takes a value of one if the CEO of the sample firm was working or studying in countries or regions outside the Chinese mainland, and zero otherwise. *CEOFE_L* equals the natural logarithm of one plus the total year duration of the CEO's foreign experience. Following Giannetti et al. (2015), we do not view it as foreign working experience if the CEO held a position in foreign subsidiaries or agencies of Chinese companies. We consider that the foreign educational experience is the CEOs' studying experience to obtain a master's or doctoral degree in foreign countries or regions.

TABLE 3 Distribution of CEO's foreign experience.

Countries/Regions	Foreign working experience	Foreign educational experience	Foreign integrated experience	Total
Australia	1			1
Canada	4	1		5
France	3			3
Hong Kong	1			1
Italy		4		4
Japan	3			3
Russia		4		4
Taiwan		8		8
United Kingdom		15		15
United States	8	19	10	37
Total	20	51	10	81

3.2.3 Control variables

According to existing literature (Lau et al., 2016; Liao et al., 2018; Hegde and Mishra, 2019; Luo and Liu, 2020; Kong et al., 2021), our study considers the following variables including firm size (*SIZE*), the return of assets (*ROA*), market-to-book ratio (*MTB*), firm leverage (*LEV*), cash holding (*OCF*), property, plant, and equipment (*PPE*), ownership concentration (*BLOCK*), ownership restriction by the second-largest shareholder (*RESTRAIN*), board size (*BOARD*), board independence (*ID*), the duality of CEO and board chairman (*DUAL*), and whether the observation is a state-owned enterprise (*STATE*) to control other factors that affect CSR activities.

3.3 Regression models

We examine the relationship between CEOs' foreign experience and CSR by adopting the following models (1) and (2). To control for the unobservable firm-specific heterogeneity, we include firm-fixed effects in the following models.

$$RKS\_CSR_{i,t} = \alpha_0 + \alpha_1 CEOFE\_D_{i,t} + \sum \alpha_k Control_{k,i,t} + Year + Firm + \varepsilon_{i,t} \tag{1}$$

$$RKS\_CSR_{i,t} = \beta_0 + \beta_1 CEOFE\_L_{i,t} + \sum \beta_k Control_{k,i,t} + Year + Firm + \omega_{i,t} \tag{2}$$

where, subscript *i* and *t* represent firm and year, respectively. *RKS_CSR* is a dependent variable measuring firm-level quality of CSR, *CEOFE_D* and *CEOFE_L* are independent variables indicating whether the CEO has any foreign experience and the duration of the foreign experience, respectively. According to the hypotheses, we predict that the coefficients of *CEOFE_D* and *CEOFE_L* (α_1 and β_1) are positive. *Control* is a set of control variables that are associated with CSR. *Year* and *Firm* are the year and firm fixed effects, respectively. To mitigate heteroscedasticity and cluster problems, we adopt robust standard errors by clustering at the firm-level. Detailed definitions of variables are reported in Table 1.

4 Empirical results

4.1 Summary statistics

Panel A of Table 2 exhibits the results of the descriptive statistics for key variables. During the research period, the mean value of the CSR score (*RKS_CSR*) of the sample companies increased from 33.8235 to 39.3698 (not reported). Results of the standard deviation of *RKS_CSR* show that CSR performance is different across firms. Additionally, results indicate that 3.74% of observations employ CEOs with foreign experience (*CEOFE_D*), suggesting that Chinese listed companies are short of CEO talent with foreign experience. The mean value of foreign experience duration (*CEOFE_L*) for returnee CEOs is 1.3828. Regarding firm performance, the average *ROA* (*MTB*) of sample firms is 4.21% (1.8390). Regarding ownership structure, the average largest shareholder holds 39.2943% of total outstanding shares (*BLOCK*), which is approximately 16 times the mean percentage ownership of the second-largest shareholders (*RESTRAIN*). These figures suggest that Chinese ownership structures are highly concentrated, such that the largest shareholder can dominate listed companies. Regarding board governance, the average (median) board has 9.7460 (9.0000) members (not reported). Independent directors account for about one-third of total board members (*ID*). This figure suggests that Chinese companies adopt the minimum level of independent directors required by the China Securities Regulatory Commission. Of the sample companies, 16.12% hire CEOs who also serve as chairpersons of the board (*DUAL*). Besides, the government or state agency controls approximately 63.79% of listed companies (*STATE*).

Panel B and C of Table 2 report the results of univariate analysis. First, we compare the mean of *RKS_CSR* between firms with and without returnee CEOs (*CEOFE_D*) in Panel B of Table 2. The results show that the values in the subsample for those without returnee CEOs are higher than those for the subsample with returnee CEOs, but the difference is insignificant. Furthermore, we present the mean differences on *RKS_CSR* according to the duration of CEOs' foreign experience (*CEOFE_L*) in Panel C of

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TABLE 4 Correlation metrics.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
(1) *RKS_CSR*	1.0000														
(2) *CEOFE_D*	−0.0120	1.0000													
(3) *CEOFE_L*	0.0023	**0.9455**	1.0000												
(4) *SIZE*	**0.3902**	**0.0504**	0.0364	1.0000											
(5) *ROA*	0.0295	−0.0117	−0.0179	**−0.0490**	1.0000										
(6) *MTB*	**−0.0885**	−0.0145	−0.0088	**−0.4838**	**0.3633**	1.0000									
(7) *LEV*	**0.1019**	−0.0056	−0.0045	**0.5474**	**−0.4735**	**−0.4881**	1.0000								
(8) *OCF*	**0.1158**	**0.0443**	**0.0581**	0.0180	**0.4196**	**0.1942**	**−0.2400**	1.0000							
(9) *PPE*	**0.0804**	**0.0651**	**0.0758**	**0.1120**	**−0.1699**	**−0.2042**	0.0406	**0.2977**	1.0000						
(10) *BLOCK*	**0.1570**	0.0020	0.0239	**0.2887**	**0.0597**	**−0.0897**	**0.0556**	**0.0718**	**0.0983**	1.0000					
(11) *RESTRAIN*	−0.0214	0.0370	0.0407	**0.0766**	**−0.0868**	**−0.0794**	**0.0549**	0.0053	**0.0757**	**0.3923**	1.0000				
(12) *BOARD*	**0.1487**	**−0.0451**	**−0.0451**	**0.2693**	**−0.0490**	**−0.1757**	**0.1365**	0.0383	**0.1674**	0.0283	0.0327	1.0000			
(13) *ID*	0.0043	0.0360	**0.0489**	**0.0775**	−0.0315	−0.0184	0.0369	−0.0177	**−0.0658**	**0.0593**	0.0387	**−0.1387**	1.0000		
(14) *DUAL*	**−0.0429**	0.0195	0.0380	**−0.1076**	0.0298	**0.1373**	**−0.0845**	−0.0135	**−0.1127**	**−0.1304**	**−0.0718**	**−0.1386**	**0.0673**	1.0000	
(15) *STATE*	**0.1624**	**−0.0439**	**−0.0510**	**0.3774**	**−0.1401**	**−0.2725**	**0.2556**	−0.0131	**0.1862**	**0.2778**	**0.1522**	**0.2482**	−0.0095	**−0.2212**	1.0000

Correlation coefficients in bold indicate that they are significantly different from zero at the 5% or 1% level.

TABLE 5 CEO's foreign experience and CSR (Baseline).

Variables	(1) *RKS_CSR*		(2) *RKS_CSR*	
	Coefficient	*t*-stat	Coefficient	*t*-stat
CEOFE_D	0.1070***	2.98		
CEOFE_L			0.0565**	2.06
SIZE	0.0569***	2.60	0.0572***	2.60
ROA	−0.0082	−0.08	−0.0067	−0.06
MTB	−0.0004	−0.07	−0.0006	−0.09
LEV	−0.0778	−1.15	−0.0775	−1.14
OCF	−0.0348	−0.45	−0.0346	−0.45
PPE	0.0308	0.48	0.0302	0.47
BLOCK	−0.0011	−1.08	−0.0011	−1.07
RESTRAIN	−0.0001	−0.71	−0.0001	−0.71
BOARD	0.0066	0.29	0.0065	0.28
ID	−0.0602	−0.87	−0.0622	−0.90
DUAL	−0.0053	−0.41	−0.0052	−0.39
STATE	0.0105	0.44	0.0074	0.30
Constant	2.2525***	4.60	2.2481***	4.57
Year effects	YES		YES	
Firm effects	YES		YES	
Within R^2	0.2867		0.2855	
Overall R^2	0.1720		0.1790	
N	2,165		2,165	

Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. Firm- and year-fixed effects are added in each regression model estimation. t-statistics are computed by using firm-clustering standard errors.

Table 2. By adopting the mean value of *CEOFE_L* (1.3828, representing 3.5802 years) for returnee CEOs as the cut-off, we find that the mean *RKS_CSR* is significantly higher (at the 10% level) for firms hiring CEOs with longer foreign experience compared to that for firms hiring returnee CEOs with shorter foreign experience.

Table 3 reveals the country or region and category distribution of CEOs' foreign experience. In sum, there are 81 CEOs with foreign experience during the sample period, of which 20, 51, and 10 CEOs have a foreign working, educational and integrated experience, respectively. Therefore, studying abroad is a primary mode for CEOs of Chinese listed companies to obtain foreign experience. Typically, the United States and the United Kingdom are major countries where CEOs gain foreign experience.

4.2 Correlation analysis

Table 4 reports the results of the pairwise correlation matrix among variables used in the baseline regression analyses. We show the correlation coefficients in bold if they are significantly different from zero at the 5% or 1% level. We find that the correlations among most independent variables (except for *CEOFE_D* and *CEOFE_L*) are low, and serious multicollinearity problems are less likely to exist.

4.3 Baseline results

As mentioned, Hypothesis one and two imply a positive relationship between CEOs' foreign experience and performance of CSR. We execute regression analyses of models (1) and (2) using the entire sample to validate the idea. We adopt RKS's CSR ratings (*RKS_CSR*) as the dependent variable, and the important explanatory variables are whether CEOs have foreign experience (*CEOFE_D*) and the duration of CEOs' foreign experience (*CEOFE_L*).

Table 5 presents the regression results. We find that *CEOFE_D* and *CEOFE_L* have positive and significant coefficients in the regressions of *RKS_CSR*. The results are consistent with our hypotheses that CEOs with foreign experience enhance the CSR performance, and that the longer their foreign experience, the more improved the CSR performance. The findings suggest that foreign experience helps CEOs understand the demands of stakeholders and the importance

TABLE 6 CEO's foreign experience and CSR (Instrumental variables).

Variables	(1) CEOFE_D		(2) RKS_CSR		(3) CEOFE_L		(4) RKS_CSR	
	First-stage		Second-stage		First-stage		Second-stage	
	Coefficient	t-stat	Coefficient	z-stat	Coefficient	t-stat	Coefficient	z-stat
Instruments								
EDU3	0.0837***	7.77			0.1160***	7.27		
AGE	0.0008	0.96			0.0021*	1.68		
CEOFE_DIY	0.8303*	1.86						
CEOFE_LIY					0.7651	1.11		
Instrumented								
CEOFE_D			0.4510***	3.64				
CEOFE_L							0.3223***	3.59
SIZE	0.0043	0.93	0.0871***	12.63	0.0005	0.07	0.0887***	12.82
ROA	−0.0825	−0.96	−0.2116	−1.52	−0.1798	−1.11	−0.1898	−1.32
MTB	−0.0006	−0.15	0.0112*	1.68	−0.0022	−0.39	0.0115*	1.72
LEV	−0.0322	−1.16	−0.1438***	−3.66	−0.0242	−0.51	−0.1502***	−3.79
OCF	0.1008*	1.78	0.1246	1.31	0.2025**	2.34	0.1043	1.08
PPE	0.0941***	3.76	−0.0111	−0.28	0.1593***	3.64	−0.0200	−0.49
BLOCK	−0.0005	−1.43	0.0014***	3.13	−0.0000	−0.05	0.0012***	2.64
RESTRAIN	0.0004**	2.18	−0.0009***	−3.98	0.0005*	1.87	−0.0009***	−3.84
BOARD	−0.0096	−0.55	0.0397	1.34	−0.0075	−0.32	0.0379	1.3
ID	0.0638	1.20	−0.0867	−1.02	0.1364*	1.69	−0.1019	−1.19
DUAL	−0.0153	−1.19	0.0049	0.32	−0.0088	−0.44	0.0000	0
STATE	−0.0196**	−2.33	0.0238	1.61	−0.0371***	−2.69	0.0259*	1.74
Constant	−0.3303***	−3.25	1.3906***	8.18	−0.4524***	−3.07	1.3757***	8.11
Year effects	YES		YES		YES		YES	
Industry effects	YES		YES		YES		YES	
Province effects	YES		YES		YES		YES	
R2	0.1724		0.2270		0.1579		0.2273	
N	2,165		2,165		2,165		2,165	
Tests of endogeneity								
Robust score chi2	23.8065		$p = 0.0000$		20.3747		$p = 0.0000$	
Robust regression F	24.0940		$p = 0.0000$		20.4862		$p = 0.0000$	
Test of over-identifying restrictions								
Score chi2	0.9218		$p = 0.6307$		1.62033		$p = 0.4448$	

Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. Year, industry, and province effects are added in each regression model estimation. t- and z-statistics are computed by using firm-clustering standard errors.

of CSR fulfillment, which are beneficial to the improvement of CSR performance of Chinese domestic firms they served. Moreover, as the length of CEOs' foreign experience increases, influence of foreign institutional environments on CEOs' cognition of CSR engagement becomes profound and it facilitates the improvement of CSR performance.

TABLE 7 CEO's foreign experience and CSR (Effects of country or region-level institutional factors).

Variables	(1) *RKS_CSR*		(2) *RKS_CSR*		(3) *RKS_CSR*		(4) *RKS_CSR*	
	Coefficient	*t*-stat	Coefficient	*t*-stat	Coefficient	*t*-stat	Coefficient	*t*-stat
LAW	0.0537***	3.16						
CORRUPT			0.0562***	2.83				
REVISED					0.0339***	2.73		
ORIGIN							0.1070***	2.98
SIZE	0.0569***	2.60	0.0570***	2.60	0.0570***	2.60	0.0569***	2.60
ROA	−0.0085	−0.08	−0.0087	−0.08	−0.0078	−0.07	−0.0082	−0.08
MTB	−0.0003	−0.05	−0.0005	−0.07	−0.0007	−0.10	−0.0004	−0.07
LEV	−0.0782	−1.15	−0.0776	−1.14	−0.0768	−1.13	−0.0778	−1.15
OCF	−0.0350	−0.46	−0.0351	−0.46	−0.0346	−0.45	−0.0348	−0.45
PPE	0.0308	0.48	0.0297	0.46	0.0305	0.48	0.0308	0.48
BLOCK	−0.0011	−1.09	−0.0011	−1.09	−0.0011	−1.09	−0.0011	−1.08
RESTRAIN	−0.0001	−0.72	−0.0001	−0.73	−0.0001	−0.71	−0.0001	−0.71
BOARD	0.0066	0.29	0.0068	0.3	0.0067	0.29	0.0066	0.29
ID	−0.0599	−0.87	−0.0601	−0.87	−0.0621	−0.90	−0.0602	−0.87
DUAL	−0.0055	−0.42	−0.0056	−0.42	−0.0052	−0.40	−0.0053	−0.41
STATE	0.0109	0.45	0.0101	0.42	0.0078	0.32	0.0105	0.44
Constant	2.2765***	4.64	2.2726***	4.63	2.2182***	4.51	2.2536***	4.60
Year effects	YES		YES		YES		YES	
Firm effects	YES		YES		YES		YES	
Within R^2	0.2871		0.2870		0.2863		0.2867	
Overall R^2	0.1737		0.1740		0.1706		0.1771	
N	2,165		2,165		2,165		2,165	

Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. Firm and year fixed effects are added in each regression model estimation. t-statistics are computed by using firm-clustering standard errors.

The findings are qualitatively similar with those reported in Zhang et al. (2018) and Bertrand et al. (2021). Compared with Zhang et al. (2018) which focus on the impact of returnee directors, we address the foreign experience of CEOs who exert a directly crucial influence on the CSR activities, and consider the duration of foreign experience of CEOs which is ignored by most prior literature. Differ from Bertrand et al. (2021) adopting a sample of local firms across multiple developed countries, our paper concerns about the issue in China. A single-country setting has relatively small variations in cultural and institutional aspects that are advantageous in avoiding unobserved factors contaminating the result. We also extend the study by confirming that managerial foreign experience indeed matter for CSR performance in emerging market.

Regarding economic importance, the coefficient of *CEOFE_D* is 0.1070, suggesting that CEOs with foreign experience increase the performance of CSR by 10.70%. Considering the mean value of *RKS_CSR* is 3.5655, the effect of CEOs' foreign experience on CSR accounts for 3.00% of the sample mean values of *RKS_CSR*. Besides, the estimated coefficient of *CEOFE_L* is 0.0565, and the standard deviation of *CEOFE_L* (*RKS_CSR*) for the whole sample is 0.2776 (0.2976). Therefore, one standard deviation increase in *CEOFE_L* enhances the performance of CSR by 0.0527 standard deviations (0.0565×0.2776/0.2976). The results indicate that the explanatory power of CEOs' foreign experience on CSR performance is economically significant.

Like those in prior studies of CSR (Lins et al., 2017; Kao et al., 2018; Chen T. et al., 2020), Table 5 shows the low R-squared (less than 0.4) due to the use of cross-sectional sample. Moreover, since the application of various fixed effects that may mitigate the influence of time-invariant corporate characteristics, the estimated coefficients of most of control variables are insignificant (Kong et al., 2021). We find that only firm size (*SIZE*) holds a positive and significant coefficient, showing that firms with large assets are likely to be associated with the high performance of CSR. This result is consistent with previous studies (Dang et al., 2022) that larger firms have a stronger incentive to engage in CSR to uphold their reputation. Meanwhile, this finding implies that larger firms can afford the cost of engagement of CSR

TABLE 8 CEO's foreign experience and CSR (Does directors' foreign experience matter).

Variables	(1) *RKS_CSR*		(2) *RKS_CSR*		(3) *RKS_CSR*		(4) *RKS_CSR*	
	Coefficient	*t*-stat	Coefficient	*t*-stat	Coefficient	*t*-stat	Coefficient	*t*-stat
CEOFE_D	0.1069***	2.96			0.0549	1.41		
CEOFE_L			0.0564**	2.06			0.0092	0.30
DIRFE	0.0126	0.88	0.0127	0.88	0.0123	0.85	0.0124	0.85
DIRFE× CEOFE_D					0.0520***	3.17		
DIRFE× CEOFE_L							0.0472***	3.16
SIZE	0.0556**	2.55	0.0560**	2.55	0.0558**	2.55	0.0561**	2.56
ROA	−0.0047	−0.04	−0.0032	−0.03	−0.0053	−0.05	−0.0038	−0.03
MTB	−0.0007	−0.10	−0.0008	−0.12	−0.0006	−0.09	−0.0008	−0.12
LEV	−0.0759	−1.12	−0.0755	−1.11	−0.0762	−1.12	−0.0758	−1.11
OCF	−0.0358	−0.47	−0.0357	−0.47	−0.0354	−0.46	−0.0353	−0.46
PPE	0.0292	0.45	0.0286	0.44	0.0294	0.45	0.0287	0.44
BLOCK	−0.0011	−1.09	−0.0011	−1.08	−0.0011	−1.09	−0.0011	−1.08
RESTRAIN	−0.0001	−0.74	−0.0001	−0.73	−0.0001	−0.74	−0.0001	−0.73
BOARD	0.0043	0.19	0.0042	0.18	0.0044	0.19	0.0043	0.18
ID	−0.0583	−0.86	−0.0603	−0.88	−0.0583	−0.86	−0.0603	−0.89
DUAL	−0.0050	−0.38	−0.0048	−0.36	−0.0050	−0.38	−0.0048	−0.36
STATE	0.0121	0.51	0.0090	0.37	0.0120	0.51	0.0089	0.37
Constant	2.2771***	4.66	2.2728***	4.63	2.2747***	4.65	2.2704***	4.62
Year effects	YES		YES		YES		YES	
Firm effects	YES		YES		YES		YES	
Within R^2	0.2871		0.2859		0.2872		0.2860	
Overall R^2	0.1751		0.1823		0.1775		0.1842	
N	2,165		2,165		2,165		2,165	

Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. Firm and year fixed effects are added in each regression model estimation. t-statistics are computed by using firm-clustering standard errors.

due to their larger resource availability and lesser relative costs (Wickert et al., 2016; Ting, 2021).

Overall, we consider multiply features of CEOs' foreign experience and present single-country evidence which suggests that managerial idiosyncratic characteristics can shape CSR performance.

5 Robustness check

5.1 Endogeneity

Due to the omitted variables or reverse causality, the analysis results could be biased by endogenous problems.

We adopt instrumental variables (IV) regression analyses to mitigate endogeneity arising from unobservable factors that correlate with CEOs' foreign experience. We employ the Chinese university rating where CEOs obtained their bachelor's degree, the age of CEOs, and the average values of *CEOFE_D* (*CEOFE_L*) by industry and year as instrumental variables. First, students from highly rate Chinese universities are preferred when they apply abroad. Therefore, the high rating of Chinese universities attended by CEOs in their undergraduate years is a competitive advantage for further studies or working abroad. Following Giannetti et al. (2015), we sort Chinese universities into three (*EDU3*) or four (*EDU4*, as robustness) ratings based on the ranking presented in Netbig.com, and predict that *EDU3* (or *EDU4*) is positively related to *CEOFE_D* and *CEOFE_L*. Second, the age of CEOs (*AGE*) affects their decision to go abroad. People of different ages in China have experienced different economic development or political backgrounds, thereby having different opportunities or preferences for going abroad. Third, following Lennox et al. (2012); Faccio et al. (2016), we use the average foreign experience of CEOs in the same industry and year (*CEOFE_DIY* and *CEOFE_LIY*) as an instrument.

TABLE 9 CEO's foreign experience and CSR (Alternative measures of dependent and independent variables).

Panel A: Alternative measures of dependent variables								
Variables	(1) *HEXUN_CSR*		(2) *HEXUN_CSR*		(3) *RKS_GAD*		(4) *RKS_GAD*	
	Coefficient	*t*-stat	Coefficient	*t*-stat	Coefficient	*t*-stat	Coefficient	*t*-stat
CEOFE_D	0.5830***	3.28			1.1240***	3.33		
CEOFE_L			0.2877**	2.26			0.5842**	2.25
SIZE	0.2550***	3.33	0.2571***	3.35	0.6666***	2.72	0.6705***	2.74
ROA	4.5435***	10.61	4.5504***	10.61	−0.3666	−0.32	−0.3509	−0.31
MTB	−0.0456*	−1.86	−0.0468*	−1.90	0.0438	0.61	0.0419	0.59
LEV	−0.5577**	−2.51	−0.5549**	−2.50	−0.9368	−1.29	−0.9329	−1.28
OCF	−0.5473**	−2.25	−0.5456**	−2.24	−0.1452	−0.20	−0.1437	−0.19
PPE	−0.6270***	−2.71	−0.6304***	−2.72	0.5393	0.75	0.5327	0.74
BLOCK	−0.0020	−0.61	−0.0019	−0.60	−0.0169	−1.52	−0.0169	−1.51
RESTRAIN	0.0015**	2.08	0.0015**	2.08	−0.0003	−0.19	−0.0003	−0.18
BOARD	−0.1046	−1.19	−0.1052	−1.19	0.1765	0.68	0.1754	0.67
ID	0.0518	0.23	0.0402	0.18	−1.1198	−1.47	−1.1417	−1.49
DUAL	0.0370	0.62	0.0388	0.65	0.0231	0.14	0.0252	0.15
STATE	0.0034	0.03	−0.015	−0.13	0.1192	0.43	0.0861	0.30
Constant	−1.2300	−0.71	−1.2542	−0.72	−7.6529	−1.39	−7.7003	−1.39
Year effects	YES		YES		YES		YES	
Firm effects	YES		YES		YES		YES	
Within R^2	0.5560		0.5543		0.2409		0.2398	
Overall R^2	0.3476		0.3537		0.1675		0.1737	
N	2,149		2,149		2,165		2,165	
Panel B: Alternative measures of independent variables								
Variables	(1) Removing observations that CEO has Hong Kong or Taiwan experience		(2) Removing observations that CEO has Hong Kong or Taiwan experience		(3) Viewing CEO's Hong Kong or Taiwan experience as non-foreign experience		(4) Viewing CEO's Hong Kong or Taiwan experience as non-foreign experience	
	Coefficient	*t*-stat	Coefficient	*t*-stat	Coefficient	*t*-stat	Coefficient	*t*-stat
CEOFE_D	0.0974**	2.50			0.0964**	2.48		
CEOFE_L			0.0502*	1.70			0.0491*	1.65
SIZE	0.0566***	2.58	0.0569***	2.58	0.0572***	2.62	0.0575***	2.62
ROA	−0.0123	−0.11	−0.0108	−0.10	−0.0097	−0.09	−0.0083	−0.08
MTB	−0.0004	−0.06	−0.0005	−0.08	−0.0005	−0.07	−0.0006	−0.09
LEV	−0.0847	−1.24	−0.0846	−1.24	−0.0785	−1.16	−0.0784	−1.16
OCF	−0.0295	−0.38	−0.0294	−0.38	−0.0355	−0.46	−0.0354	−0.46
PPE	0.0411	0.64	0.0409	0.63	0.0312	0.49	0.031	0.48
BLOCK	−0.0011	−1.04	−0.001	−1.03	−0.0011	−1.08	−0.0011	−1.07
RESTRAIN	−0.0001	−0.72	−0.0001	−0.72	−0.0001	−0.70	−0.0001	−0.70
BOARD	0.0068	0.29	0.0067	0.29	0.0070	0.31	0.007	0.30

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TABLE 9 (*Continued*) **CEO's foreign experience and CSR (Alternative measures of dependent and independent variables).**

Variables	(1) Removing observations that CEO has Hong Kong or Taiwan experience		(2) Removing observations that CEO has Hong Kong or Taiwan experience		(3) Viewing CEO's Hong Kong or Taiwan experience as non-foreign experience		(4) Viewing CEO's Hong Kong or Taiwan experience as non-foreign experience	
	Coefficient	*t*-stat	Coefficient	*t*-stat	Coefficient	*t*-stat	Coefficient	*t*-stat
ID	−0.0563	−0.82	−0.0577	−0.83	−0.0615	−0.89	−0.0629	−0.91
DUAL	−0.0081	−0.61	−0.0083	−0.62	−0.0037	−0.28	−0.004	−0.30
STATE	0.0102	0.42	0.0073	0.30	0.0098	0.41	0.0069	0.28
Constant	2.2568***	4.58	2.2541***	4.56	2.2456***	4.59	2.2428***	4.57
Year effects	YES		YES		YES		YES	
Firm effects	YES		YES		YES		YES	
Within R^2	0.2855		0.2845		0.2859		0.2850	
Overall R^2	0.1733		0.1800		0.1734		0.1801	
N	2,156		2,156		2,165		2,165	

Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. Firm and year fixed effects are added in each regression model estimation. t-statistics are computed by using firm-clustering standard errors.

Table 6 reports the IV regression results. Columns (1) and (3) show the first-stage regression results by regressing CEOs' foreign experience (*CEOFE_D* or *CEOFE_L*) on instrumental variables and all control variables. We find that the instrumental variables have consistent coefficients with our predictions. The ratings of universities where CEOs obtained their bachelor's degree (*EDU3*) is positively and significantly related to the CEOs' foreign experience. It suggests that a highly rated university in the undergraduate period provides CEOs with competitive educational background and increases the possibility of CEOs' going abroad and the duration of foreign experience. The results do not qualitatively change if we adopt *EDU4* as an instrumental variable instead of *EDU3*. Columns (2) and (4) exhibit the second-stage regression results by adopting the performance of CSR (*RKS_CSR*) as a dependent variable. We employ instrumented *CEOFE_D* or *CEOFE_L*, derived from the first-stage regression as a key independent variable. We find that the coefficients of instrumented *CEOFE_D* and *CEOFE_L* are positive and significant at the 1% level. Besides, endogeneity test statistics, including robust score chi2 and robust regression F in the first-stage regressions, are significant at the 1% level, suggesting that variables of CEOs' foreign experience (*CEOFE_D* and *CEOFE_L*) are endogenous. Score chi2 in the test of over-identifying restrictions is insignificant, indicating that our specification models are well identified. In summary, the results reinforce our main evidence that CEOs' foreign experience improves the performance of CSR even when we mitigate the endogenous problems.

Additionally, the effect of CEOs' foreign experience on CSR could be affected by the issue of reverse causality. That is, firms that perform better in CSR activities are more willing to hire CEOs with foreign experience, or such firms are more attractive for CEOs with foreign experience. To solve this issue, we substitute CEOs' foreign experience with country-level institutional environments. When CEOs study or work abroad, sound institutional environments in foreign countries or regions increasingly shape their characteristics and values, thus playing a positive role in improving the CSR performance in their subsequent organizations. More importantly, the soundness of country and region-level institutional environments are not affected by the quality of CSR activities. Therefore, in this study, we replace the variables of CEOs' foreign experience with characteristics of institutional environments in the country or region where the CEO obtained foreign experience to control the endogenous problems caused by the reverse causality.

We adopt four country- or region-level indices regarding institutional environments of foreign countries or regions, including the rule of law (*LAW*), control of corruption (*CORRUPT*), revised anti-director index (*REVISED*), and whether the country or region has an English law origin (*ORIGIN*). The higher the value of indices, the better the institutional environments. Table 7 shows the results. We find that the estimated coefficients of the four country- or region-level variables of institutional environments are significantly positive at the 1% level, indicating that the soundness of institutional environments in the country or region where CEOs acquired their foreign experience can shape their characteristics, regulate their subsequent career behaviors and thereby enhance the performance of CSR. The results also suggest that the effect of CEOs' foreign experience on CSR is still valid even when we consider the endogeneity problem caused by reverse causality.

5.2 Controlling the impact of directors' foreign experience on CSR

Probably, firms with returnee CEOs simultaneously appoint board of directors with foreign experience as corporate elites and dutiful supervisors (Rivas, 2012). According to Giannetti et al. (2015), directors of company boards with foreign experience facilitate the

TABLE 10 CEO's foreign experience and CSR (Different categories of foreign experience).

Panel A: Whether a CEO has foreign working, educational, or integrated experience						
Variables	(1) *RKS_CSR*		(2) *RKS_CSR*		(3) *RKS_CSR*	
	Working experience		Educational experience		Integrated experience	
	Coefficient	*t*-stat	Coefficient	*t*-stat	Coefficient	*t*-stat
CEOFE_D	0.1206***	3.36	0.0875	1.34	0.1706***	7.87
SIZE	0.0617***	2.85	0.0592***	2.71	0.0575***	2.65
ROA	−0.0539	−0.50	−0.0329	−0.31	−0.0278	−0.26
MTB	0.0012	0.17	0.0001	0.02	0.0012	0.17
LEV	−0.1037	−1.54	−0.0864	−1.28	−0.0889	−1.29
OCF	−0.0203	−0.26	−0.0351	−0.45	−0.0275	−0.35
PPE	0.0386	0.59	0.0373	0.58	0.0328	0.50
BLOCK	−0.0013	−1.38	−0.0011	−1.10	−0.0014	−1.44
RESTRAIN	−0.0001	−0.71	−0.0001	−0.79	−0.0001	−0.60
BOARD	−0.0072	−0.32	0.0041	0.18	−0.0113	−0.51
ID	−0.0282	−0.40	−0.0509	−0.73	−0.0265	−0.38
DUAL	−0.0037	−0.27	−0.0036	−0.26	−0.0031	−0.23
STATE	0.0121	0.50	0.0146	0.58	0.0156	0.61
Constant	2.1848***	4.50	2.2037***	4.50	2.2834***	4.69
Year effects	YES		YES		YES	
Firm effects	YES		YES		YES	
Within R^2	0.2812		0.2838		0.2803	
Overall R^2	0.1858		0.1798		0.1876	
N	2,104		2,135		2094	
Panel B: The duration of a CEO's foreign working, educational, or integrated experience						
Variables	(1) *RKS_CSR*		(2) *RKS_CSR*		(3) *RKS_CSR*	
	Working experience		Educational experience		Integrated experience	
	Coefficient	*t*-stat	Coefficient	*t*-stat	Coefficient	*t*-stat
CEOFE_L	0.0439*	1.65	0.0692	1.17	0.1044***	6.15
SIZE	0.2468***	12.11	0.0593***	2.71	0.0577***	2.66
ROA	−0.6187***	−5.62	−0.0329	−0.31	−0.0289	−0.27
MTB	0.0208***	3.30	0.0001	0.01	0.0012	0.18
LEV	−0.2724***	−3.61	−0.0858	−1.27	−0.0893	−1.30
OCF	0.1052	1.27	−0.0347	−0.45	−0.0275	−0.35
PPE	0.1111	1.52	0.0367	0.57	0.033	0.51
BLOCK	−0.0027**	−2.25	−0.0011	−1.10	−0.0014	−1.44
RESTRAIN	0.0001	0.25	−0.0001	−0.79	−0.0001	−0.64
BOARD	0.0175	0.73	0.004	0.18	−0.0114	−0.51
ID	0.0029	0.04	−0.0519	−0.75	−0.026	−0.37

(Continued on following page)

TABLE 10 (*Continued*) CEO's foreign experience and CSR (Different categories of foreign experience).

Variables	(1) *RKS_CSR*		(2) *RKS_CSR*		(3) *RKS_CSR*	
	Working experience		Educational experience		Integrated experience	
	Coefficient	*t*-stat	Coefficient	*t*-stat	Coefficient	*t*-stat
DUAL	0.0036	0.23	−0.0033	−0.24	−0.003	−0.22
STATE	0.0144	0.55	0.0142	0.56	0.0157	0.61
Constant	−1.9429***	−4.19	2.2034***	4.50	2.2788***	4.68
Year effects	YES		YES		YES	
Firm effects	YES		YES		YES	
Within R^2	0.1778		0.2836		0.2805	
Overall R^2	0.1672		0.1808		0.1872	
N	2,104		2,135		2094	

Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. Firm and year fixed effects are added in each regression model estimation. t-statistics are computed by using firm-clustering standard errors.

adoption of advanced corporate governance practices and effectively perform monitoring functions. Therefore, they improve firm performance. To mitigate the concern that the directors' foreign experience could drive the relationship between CEOs' foreign experience and CSR, we include an additional control variable indicating the foreign experience of the board of directors (*DIRFE*) in models (1) and (2). Table 8 presents the regression results by considering the foreign experience of directors. Columns (1) and (2) include *DIRFE* as a control variable, and columns (3) and (4) include *DIRFE* and its interaction term with *CEOFE_D* or *CEOFE_L*. We find that coefficients of CEOs' foreign experience variables (*CEOFE_D* and *CEOFE_L*), in columns (1) and (2), are positive and significant at 5% or better. However, the coefficient of the directors' foreign experience variable (*DIRFE*) is insignificant. Columns (3) and (4) show that interaction terms of *DIRFE* and *CEOFE_D* (*CEOFE_L*) are statistically positive and significant. The results suggest that the impact of CEOs with foreign experience on CSR is still consistent with our hypothesis when considering directors with foreign experience. We do not find evidence that directors' foreign experience improves the performance of CSR. However, the positive relationship between a CEO's foreign experience and CSR is more pronounced in firms with directors with foreign experience.

5.3 Alternative measures of dependent and independent variables

We address robustness by adopting different measures of CSR and CEOs' foreign experience.

First, RKS discloses grades of CSR in addition to the score of CSR. Each firm-year is graded from AAA + to C (19 grades in total) based on its *RKS_CSR*. We assign a value of 19 (1) to AAA+ (C) grade indicating the highest (lowest) quality of CSR (*RKS_GAD*). Second, Hexun.com provides an evaluation of CSR performance for listed companies from five dimensions, including the responsibility of shareholders, employees, suppliers/customs/consumers, environment, and society. By assigning a different weight for each dimension, Hexun.com provides an aggregate CSR score (*HEXUN_CSR*) for Chinese listed companies. Panel A of Table 9 reports regression results by using *RKS_GAD* and *HEXUN_CSR* as an alternative dependent variable. We find consistent results that CEO's foreign experience (*CEOFE_D* and *CEOFE_L*) is positively and significantly related to alternative proxies for CSR performance (*RKS_GAD* or *HEXUN_CSR*).

Additionally, Panel B of Table 9 exhibits the results by re-considering the definition of CEOs' foreign experience. Hong Kong Special Administrative Region and Taiwan have an economic, cultural, and political close relationship with Chinese mainland. In columns (1) and (2), we remove observations where CEOs have Hong Kong or Taiwan experience, whereas, in columns (3) and (4), we view CEOs' Hong Kong or Taiwan experience as non-foreign experience. Results show robust evidence that CEOs' foreign experience (*CEOFE_D* and *CEOFE_L*) enhances CSR performance (*RKS_CSR*).

6 Further analyses

6.1 Effects of different categories of CEO's foreign experience

We investigate the heterogeneous influence of different categories of CEOs' foreign experience on CSR, dividing their foreign experience into foreign working, educational and integrated experience. Panels A and B of Table 10 report regression results by using *CEOFE_D* and *CEOFE_L*, respectively. Column (1) focuses on the effect of CEOs' foreign working experience on CSR. Column (2) examines the effect of CEOs' foreign educational experience on CSR. Column (3) tests the effect of CEOs' foreign integrated experience on CSR. Thus, in each columns the remaining two parameters are not included, respectively.

Results in Panel A of Table 10 show that coefficients of *CEOFE_D* in columns (1) and (3) are positive and significant, whereas the coefficient of *CEOFE_D* in column (2) is insignificant. The results suggest that, compared to CEOs' foreign educational experience, their foreign working and integrated experiences enhance CSR performance significantly. In Panel B of Table 10, we find the same qualitative

TABLE 11 CEO's foreign experience and CSR (Moderating effects of provincial legal environment and auditing quality).

Panel A: Effects of the interaction terms								
Variables	(1) *RKS_CSR*		(2) *RKS_CSR*		(3) *RKS_CSR*		(4) *RKS_CSR*	
	Coefficient	*t*-stat	Coefficient	*t*-stat	Coefficient	*t*-stat	Coefficient	*t*-stat
CEOFE_D	−0.0293	−0.37			0.0967**	2.49		
CEOFE_L			−0.0652	−1.07			0.0444	1.52
LEI	−0.0047	−1.09	−0.0050	−1.14				
CEOFE_D×LEI	0.0170*	1.80						
CEOFE_L×LEI			0.0142**	2.26				
BIG4					−0.0120	−0.32	−0.0118	−0.31
CEOFE_D× BIG4					0.0899**	2.20		
CEOFE_L× BIG4							0.0775**	2.52
SIZE	0.0572***	2.61	0.0577***	2.62	0.0562**	2.54	0.0566**	2.55
ROA	−0.0087	−0.08	−0.0085	−0.08	−0.0067	−0.06	−0.0058	−0.05
MTB	−0.0002	−0.03	−0.0003	−0.05	−0.0007	−0.10	−0.0009	−0.13
LEV	−0.0831	−1.22	−0.0846	−1.24	−0.0775	−1.14	−0.0769	−1.13
OCF	−0.0335	−0.44	−0.0330	−0.43	−0.0351	−0.46	−0.0345	−0.45
PPE	0.0363	0.57	0.0356	0.55	0.0310	0.48	0.0306	0.48
BLOCK	−0.0011	−1.11	−0.0011	−1.09	−0.0011	−1.09	−0.0011	−1.08
RESTRAIN	−0.0001	−0.77	−0.0001	−0.85	−0.0001	−0.71	−0.0001	−0.72
BOARD	0.0026	0.11	0.0026	0.11	0.0063	0.27	0.0061	0.27
ID	−0.0528	−0.77	−0.0534	−0.78	−0.0593	−0.86	−0.0609	−0.88
DUAL	−0.0053	−0.40	−0.0059	−0.44	−0.0061	−0.46	−0.0060	−0.45
STATE	0.0054	0.21	0.0022	0.08	0.0098	0.40	0.0065	0.26
Constant	2.2880***	4.68	2.2821***	4.64	2.2709***	4.57	2.2645***	4.54
Year effects	YES		YES		YES		YES	
Firm effects	YES		YES		YES		YES	
Within R^2	0.2898		0.2889		0.2869		0.2859	
Overall R^2	0.1529		0.1598		0.1629		0.1721	
N	2,165		2,165		2,165		2,165	
Panel B: Moderating effect of the *LEI*								
Variables	(1) *RKS_CSR*		(2) *RKS_CSR*		(3) *RKS_CSR*		(4) *RKS_CSR*	
	Low *LEI*		High *LEI*		Low *LEI*		High *LEI*	
	Coefficient	*t*-stat	Coefficient	*t*-stat	Coefficient	*t*-stat	Coefficient	*t*-stat
CEOFE_D	0.0674*	1.67	0.1661***	2.99				
CEOFE_L					0.0285	1.06	0.1034**	2.50
SIZE	0.0412	1.59	0.0650	1.55	0.0413	1.60	0.0651	1.55
ROA	0.0801	0.58	0.0508	0.24	0.0804	0.59	0.0661	0.30
MTB	0.0012	0.13	−0.0020	−0.26	0.0009	0.09	−0.0021	−0.28

(Continued on following page)

TABLE 11 (*Continued*) CEO's foreign experience and CSR (Moderating effects of provincial legal environment and auditing quality).

Variables	(1) *RKS_CSR*		(2) *RKS_CSR*		(3) *RKS_CSR*		(4) *RKS_CSR*	
	Low *LEI*		High *LEI*		Low *LEI*		High *LEI*	
	Coefficient	*t*-stat	Coefficient	*t*-stat	Coefficient	*t*-stat	Coefficient	*t*-stat
LEV	−0.0122	−0.14	−0.2073*	−1.70	−0.0118	−0.13	−0.2047*	−1.68
OCF	−0.0665	−0.59	0.0027	0.02	−0.0653	−0.58	−0.0006	0.00
PPE	0.0030	0.04	0.1397	1.25	0.0043	0.05	0.1281	1.13
BLOCK	−0.0010	−0.87	−0.0011	−0.49	−0.0010	−0.88	−0.0010	−0.48
RESTRAIN	−0.0002	−0.63	−0.0001	−0.35	−0.0002	−0.60	−0.0001	−0.40
BOARD	−0.0279	−0.86	0.0514	1.55	−0.0290	−0.89	0.0531	1.59
ID	−0.0201	−0.26	−0.1468	−1.22	−0.0217	−0.29	−0.1494	−1.24
DUAL	0.0006	0.03	−0.0103	−0.57	0.0019	0.10	−0.0137	−0.73
STATE	−0.0074	−0.20	0.0688***	3.68	−0.0114	−0.30	0.0695***	3.72
Constant	2.5993***	4.49	2.0481**	2.19	2.6025***	4.49	2.0436**	2.18
Year effects	YES		YES		YES		YES	
Firm effects	YES		YES		YES		YES	
Within R^2	0.3037		0.2994		0.3030		0.2978	
Overall R^2	0.1004		0.2063		0.1026		0.2154	
N	1,206		959		1,206		959	
Panel C: Moderating effect of the *BIG4*								
Variables	(1) *RKS_CSR*		(2) *RKS_CSR*		(3) *RKS_CSR*		(4) *RKS_CSR*	
	BIG4 = 0		*BIG4* = 1		*BIG4* = 0		*BIG4* = 1	
	Coefficient	*t*-stat	Coefficient	*t*-stat	Coefficient	*t*-stat	Coefficient	*t*-stat
CEOFE_D	0.1002***	2.58	0.1465***	3.44				
CEOFE_L					0.0466	1.59	0.0940***	3.61
SIZE	0.0548**	2.36	0.1297	1.58	0.0551**	2.36	0.1308	1.6
ROA	0.0348	0.3	−0.3779	−0.84	0.0374	0.32	−0.3840	−0.85
MTB	−0.0003	−0.04	−0.0109	−0.6	−0.0006	−0.07	−0.0109	−0.6
LEV	−0.0460	−0.62	−0.2789	−1.21	−0.0446	−0.6	−0.2804	−1.21
OCF	−0.0502	−0.62	0.3160	1.37	−0.0496	−0.61	0.3194	1.38
PPE	0.0211	0.31	−0.0998	−0.45	0.0204	0.3	−0.0995	−0.45
BLOCK	−0.0018*	−1.79	0.0063	1.49	−0.0017*	−1.78	0.0063	1.5
RESTRAIN	−0.0001	−0.53	0.0004	0.82	−0.0001	−0.5	0.0003	0.64
BOARD	−0.0001	0	−0.0430	−0.67	−0.0002	−0.01	−0.0435	−0.68
ID	0.0047	0.08	−0.5221**	−2.07	0.0019	0.03	−0.5194**	−2.06
DUAL	−0.0117	−0.82	0.0327	0.9	−0.0115	−0.8	0.0322	0.88
STATE	0.0164	0.62	−0.0791	−1.49	0.0125	0.46	−0.0789	−1.49
Constant	2.2707***	4.39	0.8096	0.42	2.2673***	4.36	0.7873	0.41
Year effects	YES		YES		YES		YES	
Firm effects	YES		YES		YES		YES	

(Continued on following page)

TABLE 11 (*Continued*) **CEO's foreign experience and CSR (Moderating effects of provincial legal environment and auditing quality).**

Variables	(1) *RKS_CSR*		(2) *RKS_CSR*		(3) *RKS_CSR*		(4) *RKS_CSR*	
	BIG4 = 0		*BIG4 = 1*		*BIG4 = 0*		*BIG4 = 1*	
	Coefficient	*t*-stat	Coefficient	*t*-stat	Coefficient	*t*-stat	Coefficient	*t*-stat
Within R^2	0.2954		0.3032		0.2939		0.3036	
Overall R^2	0.1232		0.0802		0.1283		0.0881	
N	1819		346		1819		346	

Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. Firm and year fixed effects are added in each regression model estimation. t-statistics are computed by using firm-clustering standard errors.

results by adopting *CEOFE_L* as an independent variable. The results suggest that the governance effect of CEOs' foreign experience on performance of CSR mainly is derived from CEOs' foreign working or integrated experience, rather than foreign educational experience. Sound institutional environments, like legal protection, governance mechanism, or market supervision in foreign countries or regions where CEOs obtained their foreign experience improve CEOs' ethical concept and management philosophy in their career. It is more likely that CEOs care about the firm's long-term development and enhance the performance of CSR if they were sent to foreign countries or regions with better institutional characteristics. Therefore, compared to CEOs' foreign educational experience, their foreign working experience impacts CSR more profoundly and directly (Conyon et al., 2019). Besides, CEOs' foreign educational experience affects CSR performance only when CEOs have foreign working experience simultaneously (also called as foreign integrated experience).

6.2 Effects of the provincial legal environment and audit quality

We further analyze CEOs' foreign experience and CSR by considering several external governance factors. First, to examine the effect of the provincial legal environment on the relationship between CEOs' foreign experience and CSR, we include the legal environment index (*LEI*), indicating the quality of institutional regulations in the province where the sample firm is located. Besides, as a mechanism of corporate governance, external auditing monitors and advises firm operations. Therefore, auditing quality potentially affects the effect of CEOs' foreign experience on the performance of CSR. We adopt a dummy variable that equals one if the observation hires a Big 4 (including Deloitte, Ernst and Young, KPMG, and PricewaterhouseCoopers) auditor, and zero otherwise (*BIG4*).

We report, in Panel A of Table 11, the regression results by including the interaction terms between CEOs' foreign experience and *LEI* or *BIG4* and their coefficients are positive and significant at the 10% level or better. It suggests that CEOs' foreign experience plays a governance role on CSR performance in firms with good external governance mechanisms. Specifically, the effect of CEOs' foreign experience on CSR is more pronounced for firms located in provinces with sound legal environments or for those audited by a Big four auditor. As a robustness check, we split our sample into two sub-samples according to the median value of *LEI* in Panel B of Table 11 and the value of *BIG4* in Panel C of Table 11, respectively. Coefficients of CEOs' foreign experience are positive and significant in sub-samples with a high-quality provincial legal environment or external auditing. Notably, the magnitudes of coefficients of CEOs' foreign experience in firms with high-quality legal environment and external auditing are even larger than those in firms with low-quality legal and auditing governance. Taken together, the evidence indicates that CEOs' foreign experience exerts a positive effect on CSR especially for firms with better external governance. High-quality provincial legal environment and external auditing provide a sound governance setting under which CEOs' foreign experience effectively enhances the performance of CSR.

7 Conclusion

Our paper investigates the impact of CEOs' foreign experience on the performance of CSR by using recent data of Chinese listed companies. The recent Chinese institutional environment offers an appropriate research setting to consider the effect of foreign background of senior executives on corporate behaviors. We manually collect comprehensive data of CEOs' foreign experience in Chinese listed firms from 2011 to 2014. Results show that firms hiring CEOs with foreign experience have significantly increased CSR performance. Additionally, the longer the CEO's foreign experience, the better the firm's CSR performance. The results are consistent with our hypotheses that foreign experience enhances CEOs' capacity to recognize critical information, provides CEOs with increased cognition of CSR, and improves the performance of CSR. The results are robust to endogenous tests, additional control for directors' foreign experience, and alternative measures of key variables. Furthermore, we differentiate the categories of foreign experiences. Compared to CEOs' foreign educational experience, CEOs' foreign working and integrated experience are significantly associated with better CSR performance. Evidence of heterogeneity tests shows that the positive impact of CEOs' foreign experience on CSR performance is more pronounced for firms in provinces with better legal environments and for those audited by a Big four auditor.

Our study contributes to the literature that CEOs' foreign experience is significantly associated with better performance of CSR and offers a new research perspective of the economic consequences of CEOs' foreign experience. The results have several implications for Chinese listed companies and their stakeholders. Specifically, our research demonstrates the positive relationship between CEOs' foreign experience and CSR performance. This finding is beneficial to firms that are keen on hunting returnee talents and supports the implementation of China's brain gain policies. Meanwhile, we find that CEOs' foreign working experience improves CSR performance implying that foreign working experience is a vital criterion for corporate recruitment of returnees compared to foreign educational experience. For results of heterogeneity, they inspire stakeholders to concern about the compatibility between internal governance mechanisms (employing returnee CEOs) and external governance factors (legal environment and auditing quality).

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: https://cn.gtadata.com/.

Author contributions

YZ: Conceptualization, Data curation; Methodology; Writing original draft. LD: Reviewing and editing the paper; Funding acquisition. All authors have given approval to the final version of the manuscript.

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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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Sustainability reporting indicators used by oil and gas companies in GCC countries: IPIECA guidance approach

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The purpose of this article is to assess the quality of the sustainability reporting indicators used by oil and gas companies (OGCs) in Gulf Cooperation Council (GCC) countries. This study utilizes the International Petroleum Industry Environmental Conservation Association (IPIECA) guidance as a new robust methodology to assess the quality of sustainability reporting, which is considered a comprehensive benchmark that directly relates to the oil and gas sector. This study conducts a content analysis of the sustainability reports published by OGCs in GCC countries for the 2016–2018 period. The results reveal that the quality of the sustainability indicators disclosed by companies is largely unsuitable. The results also show that companies fail to report detailed information on environmental indicators as the most important category for OGCs. The findings demonstrate that most OGCs in Qatar pay more attention to sustainable reporting indicators than the OGCs in other GCC countries. This study successfully addresses many previously outstanding issues regarding the quality of the sustainability reporting indicators used by OGCs in GCC countries. Hence, the findings paint a clear picture of the situation so that regulators, policymakers, and managers can correct the existing shortcomings in the quality of sustainability reporting and promote sustainability reporting guidance best practices.

KEYWORDS

GCC countries, sustainability reporting indicators, oil and gas companies, IPIECA, environmental disclosure

1 Introduction

We assess the quality of the sustainability reports published by oil and gas companies located in the oil-richest countries, namely Gulf Cooperation Council (GCC) countries. The last decade has witnessed increasing recognition of sustainability issues among companies, governments, and international organizations (Kolk 2003; Barkemeyer et al., 2009). Consequently, corporations have begun competing in terms of reporting on their sustainability practices (Kolk, 2010). A sustainability report is an institutional report presenting the performance of the organization's economic activities, social responsibility, ethical culture, environmental protection, and governance performance (Heemskerk et al., 2002). Sustainability reporting provides information to different stakeholders that can help them make decisions. Companies need to focus on these issues not only to compete in the global market (Kaspereit and Lopatta 2016) but also to satisfy the local community's needs (Michelon and Parbonetti 2012; Malik 2015; Cardoni et al., 2019). Thus, sustainability reporting can minimize the gap between companies and the community by providing sufficient information. Although the petroleum sector is one of the most important sectors in the current era, its operations have serious consequences for society and the environment (Alazzani and Wan-

Hussin 2013; George et al., 2016). Despite yielding much-needed resources, exploiting oil and gas is a double-edged sword. On the one hand, oil and gas are the main drivers of global development and progress (Haderer 2013). On the other hand, each stage of their lifecycles—including exploration, drilling, production, marketing, and end use by consumers—has a significant impact on the environment and society (Orazalin et al., 2019). These resources also play important political and economic roles that affect policymakers' decisions. Thus, the companies that operate in this vital industry have important environmental and social responsibilities and face considerable local and international pressure to produce high-quality sustainability reports (Aerts and Cormier 2009; Fernandez-Feijoo et al., 2014).

The study is timely and concentrates on a topic that indeed requires much attention. There is a dearth of research on Middle East oil and gas company's sustainability reporting and therefore, the contribution of this study makes considering such gap areas is tremendous. Thus, the value of this study is in tow folds. First the focus on GCC is really important and a valuable contribution to sustainability reporting. Second the study deconstructs the sustainability reports to analyze the key question, " what is the level of sustainability reporting by OGCs among GCC countries?". The focus on OGCs' sustainability reporting in GCC stems from several reasons. First, OGCs that are members of the GCC depend heavily on oil and gas as the main drivers of their economies. Second, one-third of the world's proven oil reserves are in GCC countries (Raouf and Luomi 2015). Third, those companies manage upstream and downstream activities of the petroleum industry, with approximately 77 percent of the world's petroleum resources (Chen 2007). In addition, the OGCs hold the majority of their respective countries' oil reserves and are the largest producers of crude oil in the world (Pirog 2007). For example, Saudi Arabia is the second-largest oil producer in the world (El-Chaarani 2019).

Another motivation for assessing the sustainability reporting of the OGCs in the GCC is that sustainability information reporting by OGCs could differ between multinational OGCs and their national counterparts, owing to the different priorities and interests of the companies. For example, the first priority of national companies is to serve the community, and thus, they pay heed to sustainability issues. Multinational OGCs report sustainability information in order to build and maintain their credibility, first and foremost with shareholders and then with their other stakeholders. This is because they face considerable pressure from international shareholders to do so (Liu et al., 2014). By contrast, national OGCsare motivated to first obtain credibility from within the community they operate in and then pay heed to the demands of other stakeholders.

We also pursue this line of research because there is a scarcity of studies on the practices of sustainability reporting by OGCs (Lertzman et al., 2013). Previous studies have focused on multinational OGCs or private companies (Spangler and Pompper 2011; Alazzani and Wan-Hussin 2013; Samuel et al., 2013; Raufflet et al., 2014) and have not conducted critical analyses of sustainability reporting by national OGCs, either globally or in the GCC countries. This study is also motivated by the growing empirical literature (e.g., Frynas 2005; Frynas 2010; Raufflet et al., 2014; Comyns and Figge 2015; Talbot and Boiral 2015; Chaiyapa et al., 2016; Shvarts et al., 2016; Gaudencio et al., 2018; Orazalin and Mahmood 2018) that explores sustainability practices in OGCs. Thus, we believe that this is the first integrated analysis and comprehensive study of the quality of the sustainability reporting indicators of OGCs in GCC countries and disclosure of the same.

The GCC is an economic and political alliance of six Middle Eastern countries: Saudi Arabia, Oman, the United Arab Emirates (UAE), Kuwait, Qatar, and Bahrain. These countries share similar characteristics in terms of their political regimes (monarchy), cultures and traditions, religion (Islam), ethnicity (Arab), and even their economies, which includes their high dependence on oil revenue (Benbouziane and Benmar 2010). Thus, as oil and gas are among the most important and productive exports for the GCC countries, this study focuses mainly on the OGCs in these six countries. These companies have been largely ignored in previous studies, likely because most of them are not publicly listed. As researchers, we identify the importance of addressing this issue to bridge the gap in the research in this area.

Our key question is: What is the level of sustainability reporting by OGCs within the GCC countries? To answer this question, we assess the sustainability reporting of the OGCs within the GCC countries against the guidance for sustainability reporting by OGCs provided by the International Petroleum Industry Environmental Conservation Association (IPIECA). We have also chosen to study the oil and gas sector because it is a major contributor to the GCC countries' economies. Additionally, oil and gas in the GCC countries accounted for nearly 33 percent of the world's proven oil reserves in 2013 (Raouf and Luomi 2015).

This paper contributes to the literature by assessing the quality of the sustainability reporting of the NOGCs in the GCC. We focus on these companies in this group because their unique characteristics differentiate them from other OGCs elsewhere. For instance, most of these companies are large, government-owned, required to follow specific rules and regulations, overseen by the government, and answerable to society. In addition to the exclusive rights that they hold to the development and exploration of oil resources within their home countries, OGCs also can decide on their degree of participation in specific activities. Further, in many cases, their motivations might include maintaining energy security, economic development, job creation, and wealth redistribution (Pirog 2007). Additionally, sustainability reporting may differ for the OGCs, because their stakeholders have different requirements and expectations regarding the same (Freundlieb and Teuteberg 2013; Miska et al., 2013). Thus, OGCs have to provide sustainability reports that satisfy their stakeholders' interests. Such reporting is part of their sustainable development objectives.

Another contribution of this research is methodological. By assessing the quality of sustainability reporting, this study goes beyond the work of prior studies by using the IPIECA guidance to assess the quality of sustainability reporting. We argue for and integrate the IPIECA guidance in this study as it can provide a comprehensive benchmark for the practices of sustainability reporting in OGCs (Rodriguez 2019). Additionally, the consensual agreement among three organizations (IPIECA, API, and the International Association of Oil and Gas Producers [OGP]) creates comprehensive guidance for sustainability reporting for these companies. The IPIECA indicators were designed to be suitable for measuring sustainability in the oil and gas sector. Thus, IPIECA indicators are directly related to OGCs. Shortall et al. (2015) indicated that selecting the appropriate sustainable indicators is a means of measuring sustainability. We elaborate on this further in

Section 3. Thus, we select this guidance to assess the quality of the sustainability reporting by the OGCs in the GCC countries, and our results show that the quality of their sustainability reporting is moderate. We also find that the environmental indicator is the most commonly reported factor, whereas the social and economic indicators are the least frequently reported factors by the OGCs in the GCC countries.

The remainder of this study is organized as follows. Section 2 presents the literature review. Section 3 describes the methodology used in the study. Section 4 presents the descriptive results and the discussion. Section 5 concludes the paper.

2 Literature review

Publishing a sustainability report gives companies a platform through which to provide their stakeholders with information about how the company addresses its strategic plans and initiatives concerning sustainability. At a minimum, sustainability reports should contain information about the economic, social, and environmental aspects and performance of a company. Further, these three aspects of sustainability reporting by necessity contain quantitative and qualitative information (Daub 2007) and strive toward improved effectiveness and efficiency (KPMG 2002; as cited in Asif et al., 2013a).

Stakeholder theory, along with institutional theory and legitimacy theory, dominates in social and environmental research (Gray et al., 1996; 2009; Spence et al., 2010). In this paper, we follow this stream of research by using a combination of strategic and institutional legitimacy theory and stakeholder theory to assess the context in which oil and gas companies operate (Comyns 2016). The stakeholder perspective considers that companies issue sustainability reports as a way of responding to stakeholder informational needs and stakeholder pressure (Deegan and Blomquist 2006). Strategic legitimacy views the attainment of legitimacy from a managerial perspective, arguing that companies strategically produce reports to gain or maintain legitimacy (Deegan, 2006). The main concept of legitimacy theory constitutes society's acceptance of the behaviors of the organization (Suchman, 1995).

The oil and gas sector has placed itself within the agenda of sustainability development and reporting, particularly since the publication of sustainability reporting guidelines like those devised by the Global Reporting Initiative (GRI) and IPIECA. Oil and gas is one of the key goods importing and exporting internationally. According to the World Bank, oil and gas products are the foremost items traded world wide, amounting to approximately USD 2 billion in daily trades (Tordo et al., 2011). The same paper reported that 90 percent of the world's oil and gas reserves and 75 percent of oil and gas production are controlled by national oil companies (NOCs). With the current trends of paying attention to sustainability issues, governments often issue objectives, policies, and a variety of regulations related to sustainability issues in the petroleum sector. NOCs need to follow these policies and objectives as well as the global initiatives and guidelines. Sometimes the choice of which objectives and regulations to adhere to is based on the particular objectives that policymakers want to realize and their relative priorities (Tordo et al., 2011).

Sustainability reporting has been studied from different perspectives. Some studies have focused on the theoretical background of sustainability reporting (Connelly et al., 2011; Onn and Woodley 2014; Rezaee 2016). Other studies refer to the development of an applicable framework for implementing sustainability practices (e.g., Asif et al., 2013b), a methodology for measuring the quality of sustainability reporting (Freundlieb et al., 2014; Michelon et al., 2015), investigating the impact of external issues such the uncertainty of economic policy (Li and Zhong, 2020), and supply chain sustainability goals (Ahmad W. N. K. et al., 2016). A few studies, such as those of Abdalla and Siti-Nabiha (2015), Chaiyapa et al. (2016), Fragouli and Jumabayev (2015), and Orazalin et al. (2019), have studied perceptions of factors that motivate improved disclosure on sustainability practices, while others have assessed sustainability reporting in different industrial sectors. Some of these studies, such as those of Frost et al. (2005), Kolk (2008), Alonso-Almeida et al. (2014), Ahmad and Hossain (2015), Ehnert et al. (2016), Raucci and Tarquinio (2015), Rudari and Johnson (2015), Nobanee and Ellili (2016), and Santos et al. (2016), have also covered the sustainability reporting of all listed companies in different industrial sectors. Kolk et al. (2001) analyzed these practices in the largest companies. The current studies also, such us Li et al. (2021) which asserted about the importance of CSR mandatory disclosure and it is significantly impact of total productivity. Further, this study also found mediating effect of R&D and innovation expenditures. Another study conducted by which develop a comprehensive corporate environmental responsibility engagement measurement, then study this issue with the firm value as well as explore the mediating effect of firm innovation on this relationship based on a sample of 496 China's A-share listed companies from 2008 to 2016. They found negative effect on firm value, and corporate innovation promotes firm value of firms with corporate environmental responsibility more than firms without corporate environmental responsibility.

A number of authors have discussed multinational OGCs' sustainability reporting (e.g., Frynas 2005; 2010; Dong and Burritt 2010; Spangler and Pompper 2011; Alazzani and Wan-Hussin 2013; Samuel et al., 2013; Raufflet et al., 2014). However, despite the fact that 75 percent of oil production is controlled by national OGCs, only a few studies have analyzed the sustainability reporting practices used by these particular companies. Examples include Lertzman et al. (2013), who covered only one national OGC in Latin America; Eljayash et al. (2012), who referred to environmental reporting by Middle Eastern companies; and Kirat (2015), who covered this issue for Qatar. Notably, numerous studies have discussed sustainability reporting for various sectors, with the oil and gas industry being the most common. This is an indicator of the importance of sustainability reporting by OGCs as well as their significance in maintaining a clean environment, supporting their communities, and enhancing their countries' respective economies. We will start our review for environment component as it is considered the main factor in the sustainability report; thus, the following sub-section will elaborate on environmental reporting.

2.1 Environmental reporting by oil and gas companies

The first stand of this review is about environmental reporting. This issue is the foremost investigated in the literature in this area with regard to OGCs (Ranangen and Zobel 2014). This is natural because issues pertaining to the environment in the oil and gas sector are deemed as sensitive. The energy sector, such as the oil and gas industry, has been known to cause irreparable damage to the environment through air pollution, ecological impacts, landform changes, and global environmental problems (Hilson and Murck 2000; Spalding-Fecher 2003). Thus, it is important to focus on environmental reporting. We begin this section by reviewing the studies that have covered OGCs' environmental reporting. Alazzani and Wan-Hussin (2013) evaluated environmental practices in eight multinational OGCs using the guidelines of sustainability reporting issued in 2006 by the GRI as a benchmark. The researchers found that OGCs exert reasonable efforts to follow the GRI guidelines regarding the environmental indicator. Along the same lines, Kolk et al. (2001) found that oil companies listed among the Fortune Global 250 report more information on environmental issues when compared to other sectors, and they focus more on climate change issues. Alciatore et al. (2006) remarked that OGCs disclose more information on environmental performance when the regulatory pressures increase and when there is a threat to the legitimacy of oil companies' continued operation. Eljayash et al. (2012), evaluated environmental disclosure by OGCs in the Middle East and North Africa. They used an index to assess the extent and quality of environmental disclosure. They found that there was a significant difference in environmental reporting among the companies; however, the level of the disclosure was low when compared with that of developed countries.

Shvarts et al. (2016) performed an analysis of Russian OGCs' environmental transparency and responsibility and reported a significant difference in the level of environmental responsibility and transparency. Dong and Burritt (2010) examined the extent and quality of social and environmental reporting practices in the Australian oil and gas industry against general and industry benchmarks. They noted that Australian OGCs have poor disclosures in terms of the extent of information they provide on social and environmental issues, and the companies failed to disclose detailed information regarding the level of participation by employees and the companies' actual achievements with regard to the quantification of targets and outputs. However, the researchers did find that the companies' disclosures on human resources-related information was appropriate.

Greenhouse gas (GHG) emissions constitute an important environmental indicator. The World Energy Council reported that in 2014, energy companies alone accounted for 35 percent of global GHG emissions (Talbot and Boiral 2015). Evaluating the quality of GHG emissions reporting, Comyns (2016) analyzed how the pressures of institutional organizations can influence multinational OGCs' reporting practices on GHG emissions. She found better quality and more extensive reporting under the EU Emissions Trading Scheme. Along similar lines, Comyns and Figge (2015) studied the data of Global Fortune 500 Index companies and found that their GHG emissions reporting quality did not significantly improve between 1998 and 2010. They also noted that the quality reporting differed under each of the seven categories of quality, and they attributed this result to information typology. Similarly, analyses of GHG emissions reporting have been conducted for other companies, including those in Brazil (Castanheira et al., 2014) and in Europe (Liesen et al., 2015), as well as Fortune 500 companies (Talbot and Boiral 2015). Generally, the studies remarked that GHG emissions reporting is still not as prevalent as it should be given the pervasiveness of OGCs' GHG emissions generation.

What can be drawn from presenting previous studies is that they tried to determine the level of disclosure of environmental issues in oil and gas companies. We believe that these studies lacking use appropriate guidance that can be used as a benchmark to assess environmental disclosure. Therefore, we believe that our current study attempted to bridge this research gap, by focusing on using the IPIECA guidance, which served very well to assess the extent of reporting on the environmental indictor in those companies. Another gap of these studies is the neglecting other two main indicators of sustainability reporting, which are health and safety indicator and social and economic indicator. So, our study addresses all the three indicators of sustainability reporting.

2.2 Sustainability reporting by oil and gas companies

The second strand of review deals with the studies that assess the level of disclosure of sustainability. Several studies have assessed the three indicators of sustainability reporting for multinational OGCs. Most of these studies focused on the largest OGCs in the world. In the following, we highlight two streams of research. The first is about the methodology used in evaluating sustainability reporting and the second stream is about the level of disclosure. The methodology studies such as Raufflet et al. (2014) used the dichotomous method to examine the world's leading OGCs' CSR practices. They found that the extent of reporting for environmental indicators was the highest (earning a score of 81 percent), followed by social and health and safety information. Likewise, Roca and Searcy (2012) conducted content analyses on 13 Canadian OGCs' CSR reports for 2008. Using the triple bottom line categories listed under the GRI indicators as the benchmark. They found that funding, donations, and GHG emissions are the most frequently reported items by the OGCs, with the average score being 74 percent. They also found that 46 percent of the Canadian OGCs included the GRI-specified indicators in their reports. The studies related to level of disclosure such as; Ahmad W. N. K. W. et al. (2016) which found inconsistencies in the sustainability information reporting among the world's largest OGCs. However, they did note that the majority of these companies (60 percent) disclosed considerable amounts of environmental information, followed by social information. Spence (2011) assessed CSR initiatives in Mexican OGCs. He concluded that the high reputational cost traditionally associated with paying adequate attention to environmental and social issues has caused OGCs to spend more on CSR activities to alleviate any negative environmental and social effects arising from their operations.

Kirat (2015) analyzed the level of CSR in OGCs located in Qatar, a GCC country. His results suggested that OGCs in Qatar engage in CSR activities by focusing on the environment, sports, education, and health, but they neglect other important activities such as labor rights, human rights, work conditions, and anti-corruption and anti-bribery measures. He stated that CSR is making rapid inroads into the Qatar oil and gas industry, and these initiatives should now rise to the next level, where the focus should be on developing—and then institutionalizing—policies and strategies.

From the above literature, we can draw that there are essential limitations in the methods that have been used in assessing the level of sustainability reporting, as well as the inappropriate benchmark used. This limitation may lead to inaccurate results. Thus, we think that the current study is more broadly and systematically in the way of focusing on all OGCs in GCC countries using IPIECA guidance, and applied more advance method, three levels of disclosure (0,1, and 2).

3 Methodology

To answer the research question and achieve the objective of the study, which is assessing the quality of sustainability reporting in OGCs, we first describe the sustainability reporting index used in this paper. Several organizations around the world have issued sustainability reporting guidelines at the international level, including the GRI (2002, 2006, 2013), industry-specific reporting guidelines (e.g., API, 2004; IPIECA, 2011), and the GHG Protocol (WRI and WBCSD, 2004).

One standardized sustainability reporting framework is the Oil and Gas Industry Guidance on Voluntary Sustainability Reporting published by IPIECA. It was issued jointly with the API and the OGP. This guidance was updated in 2011 and 2015. According to the first set of IPIECA guidelines published in 2002, the objective of IPIECA is to provide globally consistent and accepted sustainability reporting guidance. This sustainability reporting framework is globally recognized as the most widely used tool for OGCs because it is considered to be a framework that includes indicators, standard disclosures, reporting protocols, and principles that are directly related to the oil and gas sector. IPIECA is the only global guidance involving both upstream and downstream sectors (Petraglia 2011). IPIECA guidance also is applicable to integrated companies such as national OGCs that have a full value chain. Most national OGCs are integrated companies because they are involved in upstream and downstream segments (Spangler and Pompper 2011). Furthermore, the IPIECA guidance also includes specifications for the oil and gas sector, while the GRI framework may be applied to different industrial sectors (Murphy et al., 2016). IPIECA intends to assist the oil and gas industry by developing, sharing, and promoting appropriate practices in and knowledge of sustainability reporting. Additionally, the United Nations Environment Programme (UNEP) promotes the use of IPIECA's guidelines. The UNEP uses it as a communication channel to disseminate best practices in sustainability reporting. In other words, it is important to note that sustainability reporting initiatives receive support from the UN (Jenkins and Yakovleva 2006; Jones et al., 2007; Boasson 2009; Emeseh 2009; Tuodolo 2009).

The latest edition of this guidance developed by IPIECA was published in 2015 and consists of three main indicators: the environment; health and safety; and social and economic issues. Each of these indicators includes several sub-indicators and items, comprising a total of 34 items in the guidance. The first refers to the environment, which comprises three sub-indicators: climate change and energy, ecosystem services, and local environmental impact. The second is health and safety, which is subdivided into three sub-indicators: health and environmental risks; workforce protection; and process safety and asset integrity. The last refers to social and economic issues, which comprises five sub-indicators: community and society, human rights, local content, business ethics and transparency, and labor practices. This study uses the 2015 edition of IPIECA's reporting guidelines to **assess** the quality of the sustainability reporting conducted by OGCs in the GCC countries.

Voluntary reporting, such sustainability reporting, is assessed using different methodologies. Some studies have conducted content analyses of CSR performance by using the dichotomous method, which takes the value of 1 if the item is present and 0 otherwise. Examples include the work of Cooke (1989), Meek et al. (1995), and Asif et al. (2013a). While studies such as those carried out by Deegan and Gordon (1996) and Haniffa and Cooke (2005) have conducted content analyses using sentences and words, others, such as those by Arcay and Vazquez (2005) and Eng and Mak (2003), have assigned points to each item of the index based on the importance of that item to the users. The content of the information in the report alone is not a sufficient condition to assess its quality and extensiveness (Toms 2002). Assessing quality reporting could be based on the nature and meaning of reporting in addition to the stakeholders' messages (Tregidga et al., 2012). Thus, measuring the quantitative and qualitative aspects of the information gives an idea of the quality and extensiveness of the report (Hossain et al., 2005). Hrasky (2012) noted that companies that rely more on charts and graphs in their sustainability reports convey more information on their actual impacts and accomplishments.

The qualitative and quantitative reporting assessed in prior studies used different methods. Cheng and Courtenay (2006) used the dichotomous method for examining the qualitative and quantitative information. Likewise, Beck et al. (2010) assessed the quality reporting by using the content and the volume of the information along with classifying the items into categories and subcategories, while Clarkson et al. (2008), Clarkson et al. (2013), and Plumlee et al. (2015) evaluated the quality of environmental reporting by examining the type and nature of the information. The type of information was classified into soft or hard (quantitative or qualitative), while the nature of the information was categorized as positive, neutral, or negative. Another study conducted by Michelon et al. (2015) assessed the quality of CSR reporting using three dimensions: information content, types of tools used to describe the information, and managerial orientation.

A variety of studies have examined the quality of reporting *via* different levels of measured qualitative and quantitative information. For example, Al-Janadi et al. (2012) used three levels; Darrell and Schwartz (1997), Guthrie et al. (1999), and Cormier and Magnan (1999) referred to four levels; Van Staden and Hooks (2007) applied five levels; and Gamble et al. (1996) and Raar (2002) used seven levels. Hassan (2010) suggested that using a ranking system with too many points could diminish the measurement's reliability, as increasing the number of points raises the chances of subjective judgments of measurement.

Therefore, our study uses three levels of disclosure (2, 1, and 0) to ensure the measurement tool's reliability. Level 2 is assigned to an item if the company discloses common items and supplemental items with qualitative or quantitative information for that item supported by graphics, charts, or tables based on the guidance. Level 1 is assigned to an item if the organization discloses only some of the common items with quantitative or qualitative information, and level 0 is assigned to an item if that item is not disclosed. Level 2 is assigned if the company provide details about the item, not only general but also the firms provide either details or quantity measurement. We do content analyses by reading the report carefully and look for every item according to the guidelines, then we scored base on the above criteria, not disclosing we score 0, general disclosure we score 1, and detail disclosure we score 2. The sustainability index score for each company is calculated according to the company's average score over

TABLE 1 Sustainability reporting Quality based on companies.

Country	Company name	Level (%)	Scores
Kuwait	Kuwait Petroleum International (Q8)	50	34 out of 68
Kuwait	Kuwait National Petroleum Co. (KNPC)	49	33
Kuwait	EQUATE Petrochemical Company (EQUATE)	38	26
Bahrain	Gulf Petrochemical Industries Company (GPIC)	54	37
Qatar	Qatar Fuel Co. (WOQOD)	35	24
Qatar	Gulf Drilling International (GDI)	44	30
Qatar	Qatar Liquefied Gas Co. (QAT GAS)	69	47
Qatar	QAPCO	62	42
Qatar	QAFAC	65	44
Qatar	QCHEM	54	37
Saudi Arabia	SAHARA	50	34
Saudi Arabia	SABIC	58	39
Saudi Arabia	FARABI	49	33
Oman	PDO	46	31
UAE	DANA GAS	52	35
UAE	PETRO RABIH	47	32
UAE	DOLPHIN	59	40
	Average score	52	
	Maximum Score (%)	69	
	Minimum Score (%)	35	

3 years. Thus, the total score of the 34 items of the index is 68 (34*2). If a company scores 68, it means that it reported 100 percent of all items in the index. ((68/68) *100), while, if a company score for example 45, it will obtained 66.18 percent ((45/68) * 100). This method of disclosure overcomes the shortcomings of the dichotomous method due to the ignorance of the extent to which each item was disclosed because it gives a score of 1 if the item is disclosed and 0 otherwise. Additionally, our chosen method avoids the weaknesses of other methods that assess the information disclosure of the items by sentences or words. In such methods, if the selected words are repeated frequently, the effectiveness of the quality reporting suffers.

We opt to analyze the sustainability reports for a period of 3 years from 2016 to 2018. We select this period to ensure that the most recent edition (the 2015 edition) of IPIECA's guidelines can be applied. Initially, all 51 OGCs in the GCC countries were to be considered for this research. However, the study omits 34 companies from the sample owing to the unavailability of their sustainability reports for the study period. Thus, the final sample selection in this study consists of 17 OGCs that published at least one sustainability report during the study period. The 17 OGCs include three companies from Kuwait, one from Bahrain, six from Qatar, three from Saudi Arabia, one from Oman, and three from the UAE. The information of five companies was collected also by external researcher to make the accuracy of the findings and contributes to the validation of the result.

4 Results and discussion

This section describes the results of this study assessing the quality of sustainability reporting for OGCs in the GCC countries.

Table 1 summarizes the descriptive statistics for the sustainability reports across companies and countries. The overall average score based on the IPIECA 2015 guidelines for the entire sample of OGC reports is 35 (52 percent). This means that the OGCs in GCC countries disclosed moderate information about their sustainability practices. This can be compared with the findings of prior studies on international OGCs, such as the work of Raufflet et al. (2014) and Ahmad W. N. K. W. et al. (2016), which noted that world-class OGCs report sufficient CSR information, with an average of more than 80 percent. Other studies have found low levels of disclosure. For example, Orazalin and Mahmood (2018) found that Russian OGCs report a low level of sustainability disclosure, with an average of 20 percent, whereas Gaudencio et al. (2018) found that Brazilian OGCs scored 41 percent on their sustainability reporting.

Table 1, Panel A, provides information on the quality of companies' sustainability reporting. The results show that the QAT GAS company obtained the highest score 47 (69 percent), followed by QAFAC, which scored 44 (65 percent). However, EQUATE scored the lowest score 26 (38 percent). One explanation for such a low score is that this company is not involved in the full streams of segments. Comparing the results of the GCC countries shows that the OGCs in

TABLE 2 Sustainability reporting score for OGCs based on items.

Items			
Environmental indicators			**44%**
	Climate Change and Energy	**46.50%**	
E1	Greenhouse gas emissions	66%	
E2	Energy use	60%	
E3	Alternative energy sources	22%	
E4	Flared gas	38%	
	Biodiversity Ecosystem Services	**36%**	
E5	Biodiversity and ecosystem services	36%	
	Water	**49%**	
E6	Fresh water	54%	
E7	Discharges to water	44%	
	Local Environmental Impact	**45%**	
E8	Other air emissions	44%	
E9	Spills to the environment	42%	
E10	Waste	92%	
E11	Decommissioning	0.02	
Health and Safety Indicators			**67.22%**
	Workforce Protection	**72.67%**	
HS1	Workforce participation	64%	
HS2	Workforce health	68%	
HS3	Occupational injury and illness incidents	86%	
	Product Safety, Health, and Environmental Risks	**63%**	
HS4	Product stewardship	63%	
	Process Safety and Asset Integrity	**66%**	
HS5	Process safety	66%	
Social and Economic Indicators			**49.73%**
	Community and Society	**54.50%**	
SE1	Local community impact and engagement	78%	
SE2	Indigenous peoples	58%	
SE3	Involuntary resettlement	0%	
SE4	Social investment	82%	
	Local Content	**68.67%**	
SE5	Local content practices	62%	
SE6	Local hiring practices	78%	
SE7	Local procurement and supplier development	66%	
	Human Rights	**37%**	
SE8	Human rights due diligence	40%	
SE9	Human rights and suppliers	38%	
SE10	Security and human rights	34%	
	Business Ethics and Transparency	**26.50%**	

(Continued on following page)

TABLE 2 (*Continued*) Sustainability reporting score for OGCs based on items.

Items			
SE11	Preventing corruption	44%	
SE12	Preventing corruption involving business partners	26%	
SE13	Transparency of payments to host governments	22%	
SE14	Public advocacy and lobbying	14%	
	Labor Practices	**62%**	
SE15	Workforce diversity and inclusion	72%	
SE16	Workforce engagement	58%	
SE17	Workforce training and development	88%	
SE18	Non-retaliation and grievance system	30%	

Qatar tend to disclose the highest level of information on their sustainability practices, with an average score of 56 percent, followed by the OGC in Bahrain (54 percent). Kuwaiti companies scored the lowest average score (45.60 percent). Comparing the results from one company to another shows that there is a significant variation in the sustainability reporting. For example, in Kuwait, Q8 scored 50 percent, while EQUATE scored only 38 percent. This result is supported by the findings of Shvarts et al. (2016), who found a significant difference in the environmental reporting done by Russian OGCs. Another explanation for the variation in reporting levels may be that certain countries actively promote sustainability reporting whereas others do not.

The sustainability reports of the OGCs in the UAE show varied scores. For instance, DOLPHIN obtained a score of 59 percent, whereas PETRO RABIH obtained 47 percent. The average scores in other countries, such Kuwait and Saudi Arabia, also show varied scores. This study includes only one company from Oman, PDO, which is the country's main government-owned petroleum company. The results show that PDO scored 46 percent, which is considered low when compared to some of the companies from Qatar, Kuwait, and the UAE. Among the Saudi petroleum companies, three companies provided sustainability reports during our study period, with an average score of 52 percent. It is noted that the largest oil and gas company in the world, which is Saudi ARAMCO, did not disclose a sustainability report in the 3-year study period, which means that the government in Saudi Arabia might not encourage OGCs to provide information on their sustainability practices.

Table 1, provides information on the quality of the countries' sustainability reporting. In general, the total score of the reporting across countries shows that there is not much significant variation in their practices. However, Qatar ranked first with an average of 55 percent (37 scores), followed by Bahrain with 54 percent. Oman and Kuwait ranked the lowest with 46 percent. On the one hand, the insignificant differences might be attributed to the six countries' shared characteristics, such as their institutional settings, corporate cultures, and dependence on oil revenues. On the other hand, Qatar's ranking might indicate that its OGCs are more committed to sustainability reporting. For example, the four pillars of Qatar's National Vision 2030 relate to sustainability. They are: human development, economic development, environmental development, and social development. These pillars are also considered to be the core elements of sustainability reporting. Accordingly, the Qatar government established various centers for sustainability development, such as one under the Ministry of Environment in 2013.

Table 2 summarizes the results pertaining to the three main sections on sustainability reporting. To gain a better understanding, we analyze the subcategories mentioned previously: environmental indicators, health and safety indicators, and social and economic indicators. The requirements for providing information on these subcategories depend on the varying degree of practicing OGCs to the quality of sustainability reporting. We find that OGCs in GCC countries report the least information on the environment (43.50 percent), followed by social and economic information (49 percent). The highest percentage is observed for the health and safety information subcategory (66 percent). This result is consistent with the study of Orazalin et al. (2019), which found that oil and gas companies in Russia report more economic information than environmental information. This result implies that OGCs in GCC countries fail to pay attention to the most important indicator of sustainability in OGCs, which is the environment. This result is consistent with the study of Dong and Burritt (2010), which reported that OGCs in Australia poorly disseminate detailed information on environmental and social issues. The lowest score for environment-related information, despite the sensitivity of the industry to environmental issues, reveals that OGCs in GCC countries may not focus on the implementation of environmental initiatives and may not be willing to disclose the relevant information due to the lack of pressure from stakeholders and consumers. This interpretation is supported by the belief that stakeholder pressure is reflected in high levels of sustainability information reporting (Cowen et al., 1987; Raucci and Tarquinio 2015). Another implication of the results may be that OGCs report more on government-regulated items, such as waste and GHG emissions, and report minimal information on items that face no regulatory oversight, such as ecosystem services, alternative energy sources, and flared gas.

Comparing the average score of the environmental sections with prior studies reveals that there are differences from one study to another. These differences are based on the methodology of assessment used, the economic development of the countries, the existence of regulation, the size of the company, and the company type (local or multinational/government-owned or private). For example, Orazalin et al.'s (2019) study found that the average score of the environmental section in Russian OGCs is 20.83 percent, while Raufflet et al. (2014) found that the average score of the environmental indicator in international oil and gas companies is 81 percent. Another study conducted by Guenther et al. (2007) found that the average score of environmental information for 19 international OGCs is 42 percent. The results of most prior studies on environmental reporting are low and consistent with the results of the current study, with the exception of the results of Raufflet et al.'s (2014) study, which contradicted those of our own. However, this contradiction might be due to the sample selection differences. For example, their study selected international OGC companies which were evaluated as A+ by the GRI in 2011, which means that they selected the highest level of international OGCs in terms of their sustainability practices.

Delving more deeply into the items included within the environmental indicator, we find that oil spills into the environment, with a score of 41 percent, tends to be one of the most underreported items by OGCs. This result is consistent with the finding of Shvarts et al. (2016), who found that only 3 out of 19 OGCs in Russia report on oil spill contingency plans. Spilling oil and any other fluids into the environment during the operational transport of oil and gas causes environmental pollution and affects sensitive ecosystems and people's livelihoods (Pereira and Mudge 2004; Orbell et al., 2007). Thus, OGCs must be vigilant to prevent spills and report on the quantity of oil or any other fluid spilled into the environment, as well as the impact and response action for that spill. The result also shows that flared gas is one of the least frequently reported items by OGCs, with a score of 38 percent. This means that most of the companies do not report sufficient information on the hydrocarbon gases flared into the atmosphere from their operations. This low level of reporting on oil spills and flared gas may due to the absence of government regulation in GCC countries. This argument is supported by Spence (2011), who stated that the failure of governments to implement regulations on the environment is one of the main factors contributing to OGCs' harm to the environment. In his report on flaring, Gervet (2007) stated that GCC countries emit high levels of flared gases despite having made progress in decreasing the amount of flared gases. Some countries, such as Qatar, have made significant strides toward reducing flared gases due to commitment from the highest level of government to improving the country's environmental impact management (Rozhkova 2011). This is an achievement unique to Qatar, and it has proven challenging to replicate elsewhere.

With regard to the health and safety indicators, the results in Table 2 show that this section scored the highest, with an overall score of 66 percent. This result is consistent with the findings of Raufflet et al. (2014), Dong and Burritt (2010), and Cardoni et al. (2019), who found higher levels of reporting information on health and safety when compared with other sections of sustainability reports. We assess the individual health and safety items and find that the most frequently reported item by the OGCs is occupational injury and illness incidents, with a score of 86 percent, whereas the least frequently reported item is product stewardship, with a score of 63 percent. This result indicates that OGCs pay considerable attention to and are more concerned with programs on workforce health, likely owing to the high degree of danger associated with these companies' operations, and due to the challenging locations of OGCs' operations, there is a high risk to human safety (Murphy et al., 2017). Thus, this high risk leads international organizations that are interested in human rights to focus on the nature of health and safety in these companies. Therefore, OGCs try to report more information on health and safety in order to avoid criticism and prevent the threat of boycotts and media campaigns from these international organizations.

The results for the reporting on social and economic items show a low score of 49 percent. The OGCs in GCC countries earn the lowest score on involuntary resettlement (0 percent), followed by public advocacy and lobbying (14 percent). This result is consistent with the findings of Cardoni et al. (2019). The lowest scoring subsection in the social and economic category is business ethics and transparency, with an average score of 26 percent. This low score indicates that most of the OGCs are government-owned companies, and there is no regulation requiring these companies to report information on preventing corruption or on the transparency of their payments to the government. Another explanation is that OGCs in GCC countries may be indifferent to the interests of society because most of them are national companies and their operations are local. This explanation is supported by Murphy et al.'s (2017) argument that international OGCs look out for the best interests of the societies in the foreign countries in which they work due to the nature of their operations in diverse communities and remote regions.

5 Conclusion and policy implications

This study's objective was to assess and understand the quality of sustainability reporting among OGCs in GCC countries. By assessing the quality of sustainability reports using the IPIECA guidelines, the results highlight that the quality of the sustainability reporting is moderate, with an average score of **35** (52 percent). We also find that reports on most environmental indicators, such as ecosystem services, climate change and energy, and local environmental impact, are lacking and show a low degree of reporting quality, followed by the social and economic indicators. However, this study finds that the quality of reporting varies from one company to another. For example, Qatar Gas Company scored 69 percent on the quality of its sustainability reporting, whereas EQUATE scored the lowest at 38 percent.

Business ethics and anti-corruption programs are important for companies to enhance their transparency and sustainability. The results show that the OGCs provided poor quality information on their business ethics and transparency. This low level of disclosure may be due to the lack of transparency regulations and anti-corruption policies and procedures in these countries. This finding is supported by Frynas (2010), who observed that the world's leading OGCs have a poor track record on reporting issues related to anti-corruption. Thus, it is advisable for GCC governments to issue regulations that encourage OGCs to create and implement anti-corruption policies.

The findings of the study conclude that there is a moderate level of awareness about the quality of sustainability reporting among OGCs in GCC countries and the catalytic role of sustainability reporting in providing a clear picture of their social, economic, and environmental performances. Furthermore, efficient sustainability reporting is vital in the decision-making process, especially in OGCs (Morhardt et al., 2002; Ramos et al., 2013). The findings also provide insight into the practice of sustainability reporting among OGCs. The first insight is that OGCs do not pay considerable attention to environmental issues in their sustainability reports despite the industry's environmental sensitivity. The second is that while OGCs are concerned to some extent with health and safety, they are not particularly concerned with social and economic issues, which indicates the failure of these companies to consider the best interests of the communities in which they work.

This study provide further implication related sustainable development in oil and gas companies. This sector is the main component of the economies of the countries of the region. Thus, these countries added in their visions the sustainability development as the main pillar of their visions. Even though, the energy has a positive role in the development of this region. However, the combustion of fossil energy sources deteriorates the environmental quality by increasing carbon and ecological footprint. Thus, this study provided implication by helping these countries to mitigating the ecological effect and suggesting to enhance the energy efficiency strategies.

In conclusion, this article contributes to the literature by assessing the level of sustainability reporting among OGCs in GCC countries, which is a topic that has been largely ignored in previous studies. This study has implications for policymakers, regulators, and company management in the GCC countries, in that it is crucial for the companies to improve their sustainability reporting practices, particularly in the areas of risk management for product safety, health and environmental risks, spills into the environment, and corruption prevention. Moreover, the low level of reporting for some important sustainability elements, such as spills of oil or other materials into the environment—which have the potential to pollute not only bodies of water but also to harm human, bird, and aquatic life—and human rights have important implications for government authorities. Furthermore, of the 51 OGCs in the GCC countries, only 17 companies issued sustainability reports during our study period. Thus, these countries' governments need to issue regulations both requiring and encouraging OGCs to report and adopt sustainability reporting best practices. However, given that our paper is based on an analysis of the available sustainability reports of only 17 OGCs in a 3-year period, our conclusions should be considered as preliminary.

Our findings on the practices of sustainability reporting in the energy sector leads us to conclude that sustainability reporting still needs to improve in order to meet best practices. More academic work is required to bridge the gaps between sustainability policy and practice in the energy industry. This is especially true of the OGCs because of the dearth of studies in this area. The endorsement and implementation of mandatory regulations may also play an essential role in enhancing the quality of sustainability disclosure.

Several interesting topics related to sustainability reporting in oil and gas offer potential avenues of study for future research. For example, the analysis of sustainability reporting can be extended to include other countries in the Middle East and North Africa in order to make a more complete comparison of differences in politics, government, culture, and economic development. Certain variables that may have an impact on the quality of sustainability reporting, such as the size of the company, its financial performance and culture, and economic development, can also be investigated. Furthermore, a future study can focus on case studies. This type of research can provide the assurance of the actual practices of sustainability in comparison with what companies disclose in their sustainability report.

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

YA write most of the parts of the paper including analyzing the data from the sustainability Reports, CSR Reports. and write the methodology section with the discussion of the results and the conclusion. Furthermore, He write the LR. AA enhanced the LR section and the discussion section.

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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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To what extent does renewable energy deployment reduce pollution indicators? the moderating role of research and development expenditure: Evidence from the top three ranked countries

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Climate change, pollution, drought, and rising seas impede the achievement of the seventh sustainable development goal SDG#7 "affordable and clean energies". To counter these threats, the use of Renewable Energy (RE) as an alternative to conventional energy plays an important role in sustainable development. In this context, the purpose of our paper is to investigate the effect of Renewable Energy deployment on environmental protection in China, The United States of America (USA), and Germany: the top three ranked countries in terms of REs production, according to RENEWABLE 2021 GLOBAL STATUSREPORT. To achieve this objective, the paper adopts a Panel fully modified OLS (FMOLS) method. Results declare that renewable energy significantly reduce pollution indicators; furthermore, we find that Research and development fully moderate this relationship. The findings of this study emphasize the importance of increasing spending on Research and development activities in the RE sector. In addition, the countries studied and countries around the world should pay greater attention to investment in research and development to support the long-term plan for advancing sustainable energy sources for feasible energy and economic development.

KEYWORDS

renewable energies, pollution indicators, China, Germany, USA, research and development (R & D)

1 Introduction

Climate change is an extreme threat to the survival of the planet and humanity in the 21st century. To deal with it, the use of renewable energies is an essential element. RE are the fastest-growing energy source, approximately, 11.2% of the world's energy consumed for heating, electricity and transportation came from modern renewable (biomass, geothermal, solar, hydro, wind and biofuels) in 2019, compared to 8.7% in 2009 (Center for Climate and Energy Solutions, 2020).

Certain past events, and even crises, provide a favorable environment for turning to renewable energy. For example, high volatility of oil prices, dependence on these foreign resources, power generation mix[1], environmental changes and significant pressure to reduce polluting gas emissions are all major concerns that have reinforced the need to convert non-renewable resources to renewable ones (Ullah et al., 2021). Without going back much in time, we take the case of the COVID-19 crisis, thus, in the midst of the COVID-19 pandemic, renewable energy production increased by about 3% (World Nuclear Industry Status Report, 2020[2]). Renewable energies are resisting the crisis. Thus, even though the crisis has stopped renewable energy projects under construction or in development, it has little effect on existing capacities. COVID-19 crisis has led to substantial reductions in global electricity demand due to movement limits, lockdowns, and the economic downturn. For example, compared to April 2019, electricity consumption decreased by 5% in the United States in April 2020 and by 12% in Germany (Mahian et al., 2021). However, this pandemic indirectly contributed to the achievement of the UN Sustainable Development Goals for 2030 (namely "SUSTAINABLE CITIES AND COMMUNITIES", "SUSTAINABLE CONSUMPTION AND PRODUCTION", "MEASURES TO COMBAT CLIMATE CHANGE", and "LAND LIFE") by enhancing the overall health and safety of cities through reducing greenhouse gas (GHG) emissions, outdoor air pollution, land pressure, and wildlife.

In 2019, China played a leading role in investment in renewable sources (83.4 billion USD), the USA a second-tier role (55.4 billion USD), (Frankfurt School-UNEP Centre, Bloomberg NEF, 2020)[3]. The increase of the share of renewable in the electricity mix (due to ambitious renewable energy policies) and the continued decline in the costs of solar and wind technologies have contributed to a strong increase in renewable energy production, especially since 2010 in Europe (such countries as the United Kingdom (+33 pts. to 41%) and Germany (+24 pts. to 41%)), China (+10 pts. to 29%), and the USA (+10 pts. to 21%) (Enerdata, 2021). Despite their high share of renewable energy in the energy mix, these countries are not really so clean. It is for all these reasons that our paper focuses on these countries.

Energy consumption and environmental quality are among the most important determinants of human development (Hung, 2021). The existing literature on the impact of RE use in the reduction of pollution indicators mostly focused on the direct impact (Magazzino et al. (2021); Destek and Aslan, (2020); Ma et al. (2021)...). While the implementation of Research and development will further promote the reduction of pollution indicators. This paper applies a Panel Fully Modified Least Squares (FMOLS) Method to explore the pollution indicators reduction caused by the use of renewable energies, and further, studies whether Renewable energies achieve the effect of reducing pollution indicators through Research and development expenditures. Similarly, as an extension of the research, this paper exploits robustness analysis, thus, we further, tested the direct and indirect effects through other measures of renewable energies. Given the extant findings, our results show a negative relationship between REs and pollution, thus, the use of renewable energies have been reduced the effect of pollution indicators. In addition, we find that Research and development fully moderate this relationship.

Our paper makes contributions to the existing literature: 1) it belongs to the literature of the generation mix, which has the merit of being very useful both on a purely scientific level and on a practical and institutional level. 2) This is the first attempt to extend the previous literature by sampling the top three renewable energy leaders (China, USA and Germany). This choice gives robustness and applicability to real contexts to the results obtained. 3) Our paper treats each pollution indicator individually, moving from the general to the specific framework. 4). And importantly, since previous studies have ignored the moderating effect of research and development in the relationship between the use of renewable energies and the reduction of pollution indicators, our paper aimed to bridge this gap in the literature. Thus, integrating research and development work into the process of the energy transition, will achieve the various long-term energy and climate objectives.

Our paper can be useful for both academics and policymakers. For academics, it can provide an empirical basis for further research into the support of RE and its role in reducing or even eliminating pollution through Research and development in order to achieve a low-carbon world. For policymakers, an overview of the policies made by these leading countries may help inform their policymaking.

With the aim of achieving the purpose of this research, the remainder of this paper proceeds as follows: Section 2 presents a discussion of practices implemented by the studied countries and gives an overview of the previous literature. Then, the study design is introduced in Section 3. The impact of RE use on air pollutants emissions and the moderating role of R&D expenditure are outlined in Section 4. Finally, the conclusion highlights the contribution of this paper, policy implications and possible future research.

2 Approaches and strategies to enhancing energy security

In this study, the research framework was developed based on the "Energy security theory". This theory shows that changes in the energy sector could profoundly alter the future energy outlook, and that the shift to renewable energy has positive climate and environmental effects. Energy security is a component of environmental security and community sustainability (Hossain et al., 2016). It is primarily concerned with whether governments have control over their energy production and supply resources. Energy security is also equated with the access of the poorest to energy services, or the mechanism that limits the dominance of a single energy system (Kuik et al., 2011). Adopting the concept of energy security is intended to emphasize the role of government and local institutions in protecting the interests of consumers, whether they are private or public entities. Energy security could be described as the state of the economy that allows for the current and future supply of both fuels and energy in a technically and economically justified manner while meeting environmental protection requirements.

1 The European Union's energy mix was composed mainly of five different sources: petroleum products (including crude oil) (35%), natural gas (24%) and renewable energy (17%). %), nuclear power (13%) and solid fossil fuels (12%).

2 Retrieved from World Nuclear Industry Status Report 2020 (worldnuclearreport.org).

3 (Frankfurt School-UNEP Centre, BloombergNEF, "GLOBAL TRENDS IN RENEWABLE ENERGY INVESTMENT 2020").

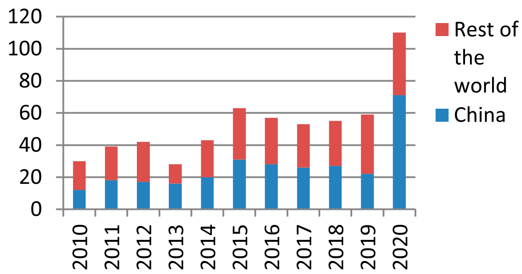

FIGURE 1
Wind capacity (Annual change, GW). Source: BP statistical reviews of world energy (2021).

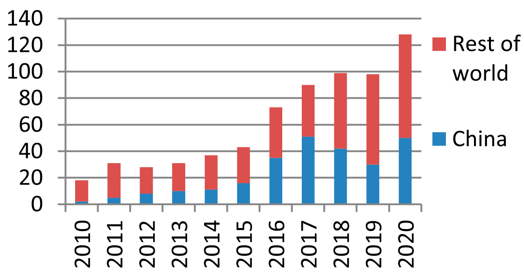

FIGURE 2
Solar capacity (Annual change, GW). Source: BP statistical reviews of world energy (2021).

2.1 Country strategies in renewable energy

China: The Chinese government has established a series of top-down policy initiatives related to environmental protection. Therefore, in 2013, the Chinese State Council established the National Action Plan for Air Pollution Control and Reduction (China State Council, 2013). In addition, in a restructuring process of the central government, the Ministry of Ecology and Environment was established and tasked with supporting better pollution control. China contributed the most to the growth of the renewable energy sector (1.0 EJ), followed by the United States (0.4 EJ) (BP statistical reviews of world energy, 2021)[4]. During the 2015 United Nations climate conference, China committed to reducing carbon intensity in 2030 by 60–65% compared to 2005 levels. Figures 1, 2 illustrate the global evolution of wind and solar capacity over the period 2010–2020. Global wind capacity has increased by 110 GW in 2020, while solar capacity is 128 GW during the same year, despite the massive disruptions associated with the global COVID-19 pandemic. Both figures prove that China accounts for nearly half of this global increase. Hence, China is the main driver of wind and solar capacity with 71 GW and 50 GW respectively in 2020.

United States of America (USA): Renewable energy represents the fastest-increasing source of energy globally and particularly in the United States, with a 90% increase between 2000 and 2020. They accounted for nearly 20% of U.S. electricity generation in 2020 on an industrial scale (Center for Climate and Energy Solutions, 2020). The United States signed the American Recovery and Reinvestment Act (ARRA) in2009 after the financial market collapse that led to the great recession. The ARRA was an unprecedented $900 billion economic stimulus package that included a series of measures for investment opportunities in renewable energy and energy efficiency (Mullen and Dong, 2022). Similarly, the proposed $1.2 trillion infrastructure bill for 2021 includes $500 million for renewable energy projects.

Several states have adopted renewable portfolio standards (RPS), with various goals and target dates. Figure 3 shows the details of state RPS programs. Thus, as of September 2020, 38 states and the District of Columbia had established an RPS or renewable energy goal, and in 12 of those states (and the District of Columbia), the requirements are for 100% clean electricity by 2050 or earlier. In addition to renewable energy standards, this map clearly shows that some states have programs in place that provide additional credits for solar or customer-installed renewable; various types of renewable space and water heating; fuel cells; energy efficiency measures and advanced fossil fuel technologies (Washington, Oregon, Michigan, Colorado, Texas, Arizona, and Utah). Other states have clean energy targets or goals, defining terms such as "carbon-free," "carbon-neutral" or "clean energy". As an example, 5 states have a clean energy standard and another 5 states have clean energy goals.

Germany: Together with France, Germany played a leading role in the Paris Agreement within and outside the European Union. They have set up various collaborative research programs, one of which is "Make Our Planet Great Again", which invites researchers from around the world to fight global warming and climate change through various projects, both large and small. Figure 4 shows the production of renewable energies in Germany for the year 2020 in terawatt hours by energy type. Wind energy has the largest share with 23.4% representing 134.5 TWh, followed by geothermal energy; Biomass; Hydropower and finally Household waste with 1.0% (5.9 TWh).

The share of renewable in gross electricity consumption in Germany has increased significantly in recent years from 36.0% in 2017 to 45.7% in 2020, far exceeding the target of 35% set for that year (BMWi, 2021). Germany has also adopted a comprehensive package of measures for funding climate-related research and innovation under this program. One of the key elements of this 2030 climate action program is the introduction of a new carbon pricing system for the transport and heat sectors starting in 2021. On 14 August 2020, Germany also introduced a coal phase-out law, aiming to reduce or even stop coal-fired power generation by 2038. Figure 5 shows the stages of production reduction. Thus, coal- and lignite-fired generation is to be reduced from about 41 gigawatts (GW) in 2019 to 15 GW each in 2022 and eight to 9 GW in 2030. The phase-out is to be achieved no later than 2038. Germany's Climate Action Plan 2050 serves as a framework for German climate policy and the achievement of the long-term goal of greenhouse gas neutrality by 2050.

Table 1 shows the renewable energy production by type of energy in the surveyed countries (2019–2020). China is the most productive country with 742.0 terawatt-hours in 2019 and 863.1 terawatt-hours in 2020, followed by the USA and Germany. The total growth rate for the

4 Retrieved from:https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2021-full-report.pdf.

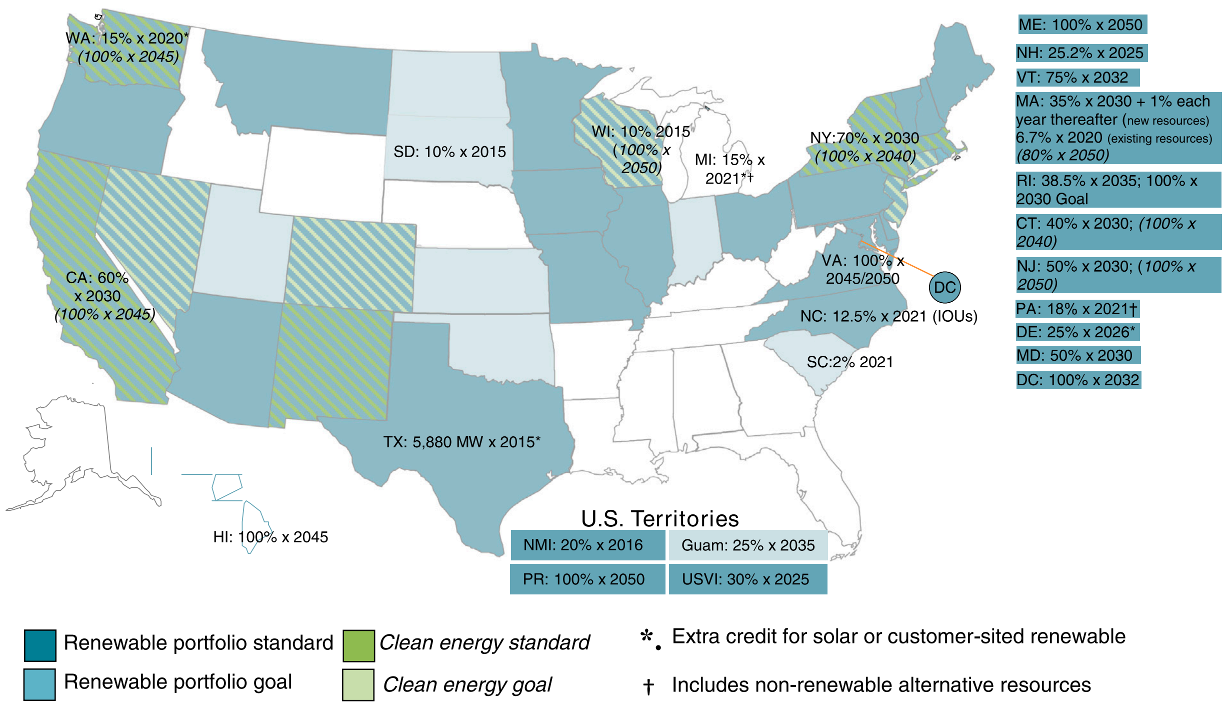

FIGURE 3
Figure 3: Summary map of Renewable and Clean Energy Standards in the USA. Source: Database of State Incentives for Renewable & Efficiency (www.dsireusa.org/ September 2020)[5]

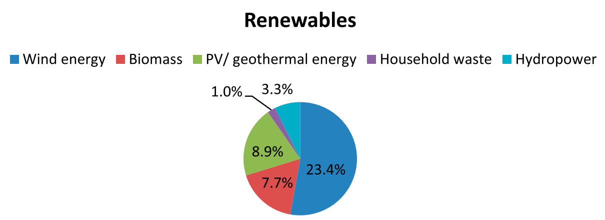

FIGURE 4
German gross renewable production in the year 2020 in (TWh). Source: Working Group on Energy Balances, (2020)[5]

year 2020, adjusted for leap years is 16.0%; 13.8% and 4.1% in China, USA and Germany respectively. To these three world leaders in renewable energy production are added India (151.2 terawatt-hours); United Kingdom (127.8 terawatt-hours); Japan (125.6 terawatt-hours) and then, Brazil (120.3 terawatt-hours) (BP Statistical Review of World Energy 2021).

2.2 Prior literature and hypotheses development

There is vast literature on innovations in the energy sector and the use of renewable energies as alternatives to traditional energies. Through an empirical study, Destek and Aslan, (2020) reported that increasing biomass energy consumption reduced carbon emissions in Germany and the United States. Likewise, Biomass energy consumption decreases long-term Carbon dioxide (CO_2) emissions in the U.S. for the monthly period 1984–2015, claimed Bilgili et al. (2016) using wavelet coherence analysis. Destek and Aslan, (2020) explored the multivariate relationship between the consumption of disaggregated renewable energy, economic growth and environmental pollution for the G-7 countries from 1991 to 2014. In this study, both a parametric and a causal approach are used, taking into account cross-sectional dependence and country-specific heterogeneity. The results showed that hydropower consumption appears to be the most effective renewable energy source for reducing carbon emissions in the G-7 countries. Ma et al. (2021) provided evidence regarding the positive effect of renewable energy in reducing carbon emissions in Germany and France, during the time when non-renewable energy consumption adds to carbon emissions. The analysis relied on several recently developed robust methods: cross-sectional correlation, panel unit root tests, panel co-integration tests, panel FMOLS and DOLS methods, panel vector error correction model, and causality testing. Based on the above description, the first hypothesis is specified as follows:

Hypothesis H_1: The use of RE has a negative impact on pollution indicators.

Throughout the world, research and development efforts must focus on renewable energies. Thus, in order to make such large-scale deployments possible, continued research and development efforts are required, with the primary goal of ensuring economic feasibility. Larger devices and power plants hold the promise of economies of scale, especially lower energy costs (Blaabjerg and Ionel, 2015). Research and development activities in the renewable energy sector include new devices and system installations for power plants. Adedoyin et al. (2020) used data from 1997 to 2015 for 16 EU countries to demonstrate how research and development spending boosts growth in the presence of renewable and non-renewable energy consumption. Blaabjerg and Ionel, (2015) present research and development opportunities for each type of renewable

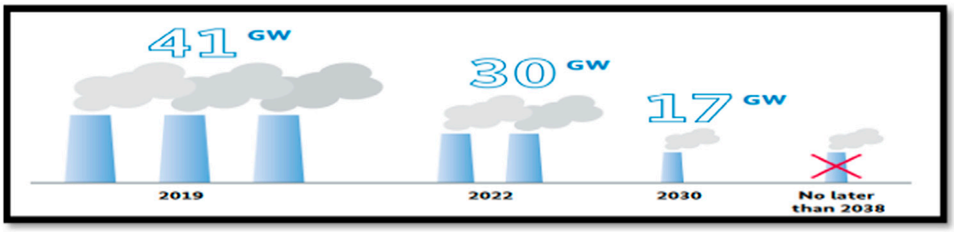

FIGURE 5
Schedule for coal phase-out in Germany. Source: BMWi (2021)

TABLE 1 Renewable energy production by source in the study countries in terawatt-hours.

	Wind	Solar	Other renewable	2019 total	Wind	Solar	Other renewable	2020total
China	405.3	224.0	112.7	742.0	466.5	261.1	135.5	863.1
USA	298.9	108.0	76.8	483.7	340.9	134.0	76.8	551.7
Germany	125.9	46.4	50.4	222.7	131.0	50.6	50.8	232.4

Data sources: BP, statistical review of world energy, (2021).

energy, for example for Wind -On-shore (Wind farm interconnection technologies, Wind energy converters based on new solid state devices), Wind-Offshore (Interconnection of onshore and offshore wind farms), Hydrogen (new methods of hydrogen storage and transport, Thermal Management) and Wave Energy (going further offshore, to greater depths and with higher waves, synergistic research with the offshore wind industry with shared infrastructures). Zhu et al. (2020) explored, for 31 Chinese provinces during 2011/2017, the relationship between renewable energy technology innovation (RETI) and air pollution through Moran's Index and spatial panel econometric models. Results indicated that investments in renewable energy technologies contribute to lower concentrations of nitrogen oxides (NOx) and respirable suspended particulate matter (PM10), whereas they are not significantly associated with sulfur dioxide (SO2). With an innovative complex ML model called "Quantum", Magazzino et al. (2021) confirmed the powerful role of biomass energy in carbon dioxide emission reductions in Germany using a linear Harrow-Hassidim-Lloyd (HHL) method, and those, considering the data set as a set of non-linear equations. The authors showed that the effect of renewable energy technology is far greater than biomass energy in reducing emissions. Lin and Zhu, (2019) investigated the link between Renewable Energy Technology Innovation (RETI) and CO_2 emissions. The results of linear regression analysis show a clear effect of RETI on CO_2 reduction based on the energy structure, similarly, observations on threshold test results confirm that the energy consumption structure dominated by coal will hinder RETI's CO_2 reduction effect. Through a case study of the United Arab Emirates, Kolsi and Al-Hiyari (2022) highlighted the CSR disclosure practices of Masdar Co. (a leading renewable energy and sustainability group in the United Arab Emirates and the Middle East region) against the Global Reporting Initiative GRI 2016 standards. The results of the study show that Masdar's Co. has boosted its brand by considering valuable CSR practices. It uses key dimensions such as ethics, law and philanthropy to manage and coordinate effective interactions with society. Masdar Co. was also found to be more successful in complying with the GRI 2016 standards in GRI 100 general disclosures, GRI 200 economic disclosures, GRI 300 environmental disclosures, and GRI 400 social disclosures. Horbach and Rammer, (2018) discussed the specific role of the regional environment of German firms in the ability to adopt energy technologies using renewable sources, using two-stage mixed effects models and the Probit model with clustered standard errors. They found that geographic proximity to renewable energy-based power generation and a region's orientation toward "green issues" are both correlated with these innovations.

However, the impact of the use of renewable energies on the protection of the environment from polluting air cannot be done in isolation; it requires heavy investment in research and development, digitization of the energy transition, conscious and intentional government policies, as well as increased opportunities for foreign investment. Research and development activities occupy the most important place. Thus, the second hypothesis to be tested in this study is as follows:

Hypothesis H_2: The implementation of R&D moderates the relationship between RE and Pollution indicators.

3 Research design

To evaluate the effect of Renewable energies on pollution indicators, we gather data on the RE use, pollution indicators such as Total greenhouse gas emissions,CO_2 emissions, Other GHG emissions, (HFC, PFC and SF6) and other variables of interest. This section presents the data, the variables and the methodology.

3.1 Data and variables

The model was implemented by collecting panel data for the period 1990–2020 depending on data availability for China, the USA and Germany. The choice of these countries is explained by the fact that they rank in the top three in terms of renewable energy production, according to the RENEWABLE 2021 GLOBAL

TABLE 2 Variables: definition, measures and data sources.

Type	Indicators	Acronyms	Periods	Number of observations	Measures	Data sources
Dependent variables	Total greenhouse gas emissions (GHG)	LNTGHG	1990–2020	88	A Thousand metric tons of CO2 equivalent excluding Land-Use Change and Forestry	World development indicators World Development Indicators | DataBank (worldbank.org)
	CO2 emissions	CO2E		90	Metric tons *per capita*	World development indicators World Development Indicators | DataBank (worldbank.org)
	Other GHG emissions, (HFC, PFC and SF6)	OGHG		66	A thousand metric tons of CO2 equivalent	World development indicators World Development Indicators | DataBank (worldbank.org)
Independent variables	Renewable energy consumption	REC		90	% of total final energy consumption	IEA Statistics IEA—International Energy Agency - IEA
	Renewable electricity output	REO		78	% of total electricity output	IEA Statistics IEA—International Energy Agency - IEA
	Alternative and nuclear energy	ANE		77	% of total energy use	IEA Statistics IEA—International Energy Agency - IEA
	Combustible renewable and waste	CRW		77	% of total energy use	IEA Statistics IEA—International Energy Agency - IEA
Control variables	GDP *per capita* growth	GDP		93	Annual %	World development indicators World Development Indicators | DataBank (worldbank.org)
	Chemicals	CH		85	% of value added in manufacturing	World development indicators World Development Indicators | DataBank (worldbank.org)
	Industry (including construction)	INDS		85	Value added (% of GDP)	World development indicators World Development Indicators | DataBank (worldbank.org)
Moderating variable	Research and development expenditure	R&D		75	% of GDP	UNESCO Institute for Statistics. UNESCO UIS

Source: Prepared by the authors.

TABLE 3 Definitions of study dependent variables.

Variables	Definitions	Source
Total greenhouse gas emissions (TGHG)	Consist of CO2 totals, excluding short-term biomass burning (such as agricultural and savanna waste burning) but including other types of biomass burning (such as forest fires, post-burn decomposition, peat fires, and drained peatland decomposition), as well as all anthropogenic sources of CH4, N2O, and fluorinated gas (HFCs, PFCs, and SF6) emissions.	World Bank (2022)
CO2 emissions (CO2E)	The emissions are the result of the combustion of fossil fuels and the manufacture of cement. They include carbon dioxide generated by the consumption of solid, liquid and gaseous fuels as well as gas flaring.	
Other greenhouse gas emissions (OGHG)	Emissions resulting from the hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF6) products.	

Source: Prepared by the authors.

TABLE 4 Statistical description of variables.

Variable	Obs	Mean	Std. Dev	Min	Max
LnTGGE	88	15.68039	.2838566	14.99117	16.35751
OGHG	66	51.6408	108.7323	−65.206	306.1404
CO2E	90	10.88079	5.880985	1.914543	20.46981
REO	78	13.08373	5.97475	3.168753	29.23177
ANE	77	8.82644	4.635684	.9187117	14.2771
CRW	77	5.801036	6.692493	.7714192	23.8631
INDS	85	31.67797	10.31246	18.04222	47.5574
CH	85	12.03748	2.117405	8.962467	16.76122
GDP	93	3.620716	4.03171	−5.454577	13.63582

TABLE 5 correlation matrix.

	REO	ANE	CRW	GDP	CH	INDS
REO	**1.0000**					
ANE	−0.4716	**1.0000**				
CRW	0.4549	-0.8003	**1.0000**			
GDP	0.4136	-0.8434	0.6257	**1.0000**		
CH	−0.2759	0.1317	-0.1220	-0.3601	**1.0000**	
INDS	0.5576	-0.8871	0.6976	0.8654	-0.5068	**1.0000**

Bold values represent that a variable has a correlation of 1.00 with itself.

STATUSREPORT. China remains the top bioenergy producer, followed by the United States and Germany. So, they are lead markets in renewable energy.

Table 2 provides the variables' definitions and measures, as well as data sources.

In order to identify the effect of renewable energy use on pollution indicators for China, the USA and Germany, we estimate econometric models where the dependent variable is pollution expressed by three indicators: Total greenhouse gas emissions; CO_2 emissions and other greenhouse gas emissions, (HFC, PFC and SF6). Each variable is defined in Table 3:

The model equation is as follows:

$$lnTGHG_{it} = \alpha_0 + \alpha_1 REO_{it} + \alpha_2 ANE_{it} + \alpha_3 CRW_{it} + \sum_{K=1}^{n} \alpha_i X_i^k + \varepsilon_{it}$$

Since our first dependent variable includes all greenhouse gas emissions, we perform a second evaluation that treats CO_2 and fluorinated gas emissions separately to find out which pollution indicator will be impacted by the use of renewable energy. This leads to the following equations.

$$OGHG_{it} = \alpha_0 + \alpha_1 REO_{it} + \alpha_2 ANE_{it} + \alpha_3 CRW_{it} + \sum_{K=1}^{n} \alpha_i X_i^k + \varepsilon_{it}$$

$$CO2E_{it} = \alpha_0 + \alpha_1 REO_{it} + \alpha_2 ANE_{it} + \alpha_3 CRW_{it} + \sum_{K=1}^{n} \alpha_i X_i^k + \varepsilon_{it}$$

To test the moderating role of Research and development in this relationship, the panel regression models took the following form:

$$lnTGHG_{it} = \alpha_0 + \alpha_1 REO_{it} + \alpha_2 ANE_{it} + \alpha_3 CRW_{it} + \alpha_4 ANE^{*}RD_{it} + \alpha_5 CRW^{*}RD_{it} + \sum_{K=1}^{n} \alpha_i X_i^k + \varepsilon_{it}$$

$$OGHG_{it} = \alpha_0 + \alpha_1 REO_{it} + \alpha_2 ANE_{it} + \alpha_3 CRW_{it} + \alpha_4 ANE^{*}RD_{it} + \alpha_5 CRW^{*}RD_{it} + \sum_{K=1}^{n} \alpha_i X_i^k + \varepsilon_{it}$$

$$CO2E_{it} = \alpha_0 + \alpha_1 REO_{it} + \alpha_2 ANE_{it} + \alpha_3 CRW_{it} + \alpha_4 ANE^{*}RD_{it} + \alpha_5 CRW^{*}RD_{it} + \sum_{K=1}^{n} \alpha_i X_i^k + \varepsilon_{it}$$

i = 1, 2. . . . . .N: the number of years.
t = 1, 2 . . . . . T, T corresponds to the number of countries.

$\alpha_0, \alpha_2 \ldots \alpha_i$ represents the slope coefficients of each variable.

ε_{it} is the residual term.

$\sum_{k=1}^{n} \alpha_i . X_i^k$ include other variables of interest which are not in line with RE use but may influence our dependent variable, i.e., GDP *per capita* growth; Chemicals and Industry.

3.2 Methodology

3.2.1 Panel unit root tests

Before building the panel regression models, we test the stability of all variables. A variety of tests exist for unit roots or stationarity in panel data sets. These include the tests of Harris-Tzavalis (1999); Breitung (2001); Fisher (2001); Levin et al. (2002) and Im et al. (2003). All of these tests have the null hypothesis that the panels have a unit root, only the Lagrangian multiplier (LM) test of Hadri (2000) has the null hypothesis that all panels are stationary (trend). Since our data set is an unbalanced panel, we adopted the Im-Pesaran-Shin and Fisher tests to check the stationarity of our variables.

3.2.2 Panel co-integration tests

We apply a co-integration test to check whether there is a long-run relationship between dependent and independent variables. We follow the residual Kao co-integration test proposed by Kao (1999). Kao's null hypothesis assumes that there is no co-integration between the variables. The panel co-integration test proposed by Kao (1999) is as:

$$y_{it} = x'_{it}\beta + z'_{it}\gamma + e_{it\,\mathrm{i=1,2\ldots,N\;et\;t=1,2\ldots,T}} \quad (1)$$

x'_{it} and y_{it} is I (1) process; z'_{it} it is an exogenous variable of fixed effect or panel fixed time trend. The ADF test proposed by Kao (1999) takes the following form:

$$ADF = \frac{t_{ADF} + \frac{\sqrt{6N}\hat{\sigma}_{it}}{2\hat{\sigma}_{\theta it}}}{\sqrt{\frac{\hat{\sigma}^2_{\theta it}}{2\hat{\sigma}^2_{it}} + \frac{3\hat{\sigma}^2_{it}}{10\hat{\sigma}^2_{\theta it}}}} \quad (2)$$

In order to verify the robustness of our results, we use another cointegration test, namely the test of Pedroni (2004) which model form will be as:

TABLE 6 Panel unit root tests.

		IPS test		Fisher type			
		(T-bar)	(p-value)	Inverse chi-squared (6) P) (p-value)	Inverse normal Z)	Inverse logit t (19) (L*)	Modified inv. Chi-squared (Pm)
Levels	CO2E	−0.4616	0.9861	2.0759 (0.9126)	2.0399 (0.9793)	2.1804 (0.9790)	−1.1328 (0.8714)
	LnTGHG	−1.0767	0.7884	2.0119 (0.9186)	1.0260 (0.8475)	0.9497 (0.8229)	−1.1513 (0.8752)
	OGHG	−2.9244	0.0098***	21.9187 (0.0013)***	−2.9210 (0.0017)***	−3.4471 (0.0014)***	4.5953 (0.0000)***
	REC	0.1852	0.9998	0.7813 (0.9926)	3.0768 (0.9990)	3.4487 (0.9987)	−1.5065 (0.9340)
	REO	0.9695	1.0000	1.0104 (0.9852)	1.0768 (0.8592)	1.0121 (0.8357)	−1.4404 (0.9251)
	ANE	−0.2639	0.9949	3.4743 (0.7474)	1.8423 (0.9673)	2.2991 (0.9835)	−0.7291 (0.7670)
	CRW	0.1129	0.9997	0.2117 (0.9998)	3.1768 (0.9993)	3.3165 (0.9982)	−1.6709 (0.9526)
	GDP	−3.2063	0.0026***	26.5711 (0.0002)***	−3.5083 (0.0002)***	−4.2589 (0.0002)***	5.9384 (0.0000)***
	CH	−2.3538	0.0617*	13.0632 (0.0420)**	−1.7206 (0.0427)**	−1.8368 (0.0410)**	2.0390 (0.0207)**
	INDS	−1.5937	0.5766	13.0246 (0.0426)**	−0.1839 (0.4271)	−0.5654 (0.2892)	2.0278 (0.0213)**
	RD	−0.8349	0.9052	1.7962 (0.9375)	1.4491 (0.9263)	1.4358 (0.9163)	−1.2135 (0.8875)
First difference	D.CO2E	−4.8754	0.0000***	70.590 (0.0000)***	−6.5679 (0.0000)***	−11.4996 (0.0000)***	18.6457 (0.0000)***
	D.LnTGHG	−5.0176	0.0000***	75.0039 (0.0000)***	−6.7922 (0.0000)***	−12.2337 (0.0000)***	19.9197 (0.0000)***
	D.REC	−3.8482	0.0002***	39.4950 (0.0000)***	−4.7960 (0.0000)***	−6.4236 (0.0000)***	9.6692 (0.0000)***
	D.REO	−4.4716	0.0000***	54.2862 (0.0000)***	−5.9920 (0.0000)***	−8.8719 (0.0000)***	13.9390 (0.0000)***
	D.ANE	−5.0016	0.0000***	69.7368 (0.0000)***	−6.9282 (0.0000)***	−11.4054 (0.0000)***	18.3992 (0.0000)***
	D.CRW	−4.1058	0.0001***	42.8482 (0.0000)***	−5.3552 (0.0000)***	−7.0112 (0.0000)***	10.6372 (0.0000)***
	D.INDS	−4.1622	0.0000***	45.1533 (0.0000)***	−5.4389 (0.0000)***	−7.3867 (0.0000)***	11.3026 (0.0000)***
	D.RD	−4.0344	0.0001***	40.6321 (0.0000)***	−5.2292 (0.0000)***	−6.6511 (0.0000)***	9.9974 (0.0000)***

Note: p-values in parentheses. $*p < 0.1/**p < 0.05/***p < 0.01$.
Source: Developed by the authors under STATA-15.

TABLE 7 Panel cointegration test.

	Model 1: LnTGHG		Model 2: CO2E		Model 3: OGHG	
	Statistic	p-value	Statistic	p-value	Statistic	p-value
Unadjusted modified Dickey-Fuller t	−3.6464	0.0001***	−3.2113	0.0007 ***	−9.1568	0.0000***
Unadjusted Dickey-Fuller t	-2.8081	0.0025 ***	−2.4925	0.0063***	-6.9049	0.0000***
Modified Phillips-Perron t	2.6333	0.0042***	2.0705	0.0192**	2.9881	0.0014***
Phillips-Perron t	−2.9495	0.0016***	−10.1516	0.0000***	−6.2206	0.0000***
Augmented Dickey-Fuller t	−3.3442	0.0004***	−7.6711	0.0000***	−4.0449	0.0000***

Note: p-values in parentheses. $*p < 0.1/**p < 0.05/***p < 0.01$.
Source: Developed by the authors under STATA-15.

$$y_{it} = \alpha_i + x_{it}^{'}\beta_i + \delta_i t + e_{it\, i=1,2\ldots,N\text{ et }t=1,2\ldots,T.} \tag{3}$$

3.2.3 Panel fully modified least squares (FMOLS)

Since the results of the Kao and Pedroni tests confirmed the cointegration between the variables, and because our model contains a small sample, we use the FMOLS method to test our research hypotheses. Kao and Chiang, (2001) have proved that FMOLS outperform for a small sample.

4 Results

This paper studies the negative relationship between RE use and pollution indicators emissions. In order to better analyze the relationship between the two, descriptive analysis, correlation analysis, unit root tests, co-integration tests, fully modified least squares (FMOLS)method, moderating effect analysis, and robustness test were carried out.

TABLE 8 Results of FMOLS.

Model1: LNTGHG				
Variable	Coefficient	Std. Error	t-Statistic	Prob
ANE	0.026143	0.011831	2.209746	0.0317**
CRW	−0.055810	0.002167	−25.75987	0.0000***
REO	0.004268	0.001250	3.413375	0.0013***
CH	−0.007966	0.006196	−1.285659	0.2045
GDP	0.004740	0.002573	1.842063	0.0714*
INDS	−0.004325	0.005627	−0.768578	0.4458
R-squared	0.978822	Mean dependent var		15.66235
Adjusted R-squared	0.975433	S.D. dependent var		0.274890
S.E. of regression	0.043086	Sum squared resid		0.092819
Long-run variance	0.001074	—	—	—
Model2: OGHG				
CRW	−21.13891	1.303234	−16.22035	0.0000***
ANE	−26.83412	1.785058	−15.03263	0.0000***
REO	1.585970	1.781726	0.890131	0.3781
CH	22.62704	1.914960	11.81594	0.0000***
INDS	3.575893	1.002620	3.566550	0.0009***
GDP	4.532951	2.712427	1.671179	0.1016
R-squared	0.913044	Mean dependent var		69.55666
Adjusted R-squared	0.903383	S.D. dependent var		117.6241
S.E. of regression	36.56147	Sum squared resid		60153.35
Long-run variance	1300.415	—	—	—
Model 3: CO2E				
CRW	−0.367093	0.046753	−7.851690	0.0000***
ANE	−0.889760	0.255300	−3.485147	0.0010***
REO	−0.031727	0.026981	−1.175913	0.2452
CH	−0.612979	0.133708	−4.584470	0.0000***
INDS	−0.237950	0.121421	−1.959713	0.0556*
GDP	−0.102186	0.055527	−1.840300	0.0717*
R-squared	0.989750	Mean dependent var		10.03589
Adjusted R-squared	0.988110	S.D. dependent var		6.189624
S.E. of regression	0.674938	Sum squared resid		22.77710
Long-run variance	0.500058	—	—	—

Note: 1) ***, **, and * denote a significance of 1%, 5%, and 10%, respectively; 2) The co-integration regression contains no constant or trend; 3) Lags and leads are set according to AIC and BIC selection criterion; 4) Results are estimated by Eviews 9.

4.1 Results of tests

The statistical descriptions of all variables used in our study are presented in Table 4. These statistics (mean, median, minimum value, maximum value, standard deviation) give us an idea of the evolution of the data over time.

Similarly, we checked the independence of the variables to ensure that there were no problems of multicollinearity that might affect our results. The correlations between the variables identified in the model are presented in Table 5. Overall, the results show no problems with collinearity between the independent variables, as multicollinearity can be a problem when the correlation is >0.80 (Kennedy, 2008). In this regard, the estimation is valid and robust.

The results of the panel unit root tests mentioned in Table 6 reveal that the p-value of all variables in 1st difference is lower than the significance level alpha = 0.01, we have to reject the null hypothesis H0, and retain the alternative hypothesis H1 of stationarity of the series. Thus, the first difference of all the variables is stationary. Only the variables "OGHG", "GDP" and "CH" are stationary in level.

TABLE 9 the moderating effect of R&D.

Model 4: LNTGHG				
Variable	Coefficient	Std. Error	t-Statistic	Prob
ANE	0.028498	0.016464	1.731005	0.0899
CRW	−0.055813	0.001914	−29.15582	0.0000
REO	0.006192	0.002034	3.043398	0.0038
R_D_ANE	0.001588	0.006011	0.264205	0.7928
R_D_CRW	−0.007510	0.001307	−5.745278	0.0000
GDP	0.001174	0.002264	0.518526	0.6065
INDS	0.009201	0.005233	1.758170	0.0851
CH	0.004284	0.006178	0.693341	0.4914
R-squared	0.986500	Mean dependent var		15.66235
Adjusted R-squared	0.983687	S.D. dependent var		0.274890
S.E. of regression	0.035109	Sum squared resid		0.059168
Long-run variance	0.000753	—	—	—
Model 5: OGHG				
ANE	−16.08958	11.21420	−1.434750	0.1591
CRW	−16.52144	1.256973	−13.14383	0.0000
REO	−2.739939	1.536315	−1.783449	0.0821
R_D_ANE	12.24579	3.633226	3.370502	0.0017
R_D_CRW	−1.375991	0.787610	−1.747046	0.0883
GDP	7.846753	1.401908	5.597196	0.0000
INDS	1.102140	3.282214	0.335792	0.7388
CH	27.01230	3.931258	6.871159	0.0000
R-squared	0.952760	Mean dependent var		69.55666
Adjusted R-squared	0.940950	S.D. dependent var		117.6241
S.E. of regression	28.58286	Sum squared resid		32679.19
Long-run variance	247.9206	—	—	—
Model 6: CO2E				
ANE	−0.519136	0.262683	−1.976285	0.0539
CRW	−0.368494	0.030543	−12.06462	0.0000
REO	0.026647	0.032461	0.820892	0.4158
R_D_ANE	−0.098185	0.095911	−1.023712	0.3111
R_D_CRW	−0.086837	0.020858	−4.163361	0.0001
GDP	−0.118245	0.036128	−3.272919	0.0020
INDS	−0.021323	0.083496	−0.255373	0.7995
CH	−0.391244	0.098579	−3.968851	0.0002
R-squared	0.992741	Mean dependent var		10.03589
Adjusted R-squared	0.991229	S.D. dependent var		6.189624
S.E. of regression	0.579687	Sum squared resid		16.12976
Long-run variance	0.191739	—	—	—

Note: 1) ***, **, and * denote a significance of 1%, 5%, and 10%, respectively; 2) The co-integration regression contains no constant or trend; 3) Lags and leads are set according to AIC and BIC selection criterion; 4) Results are estimated by Eviews 9.

Table 7 reports the results of co-integration tests. The null hypothesis of no cointegration is rejected for all models. All five tests used support the co-integration hypothesis, rejecting the null hypothesis at the 1% level. Table 7 is providing evidence that all panels of the data are cointegrated, which confirms a robust long-term association between the variables.

TABLE 10 Results of FMOLS.

Variable	Coefficient	Std. Error	t-Statistic	Prob
Model 1: LNTGHG				
REC	−0.050379	0.001125	−44.76149	0.0000
REO	0.020310	0.001479	13.73508	0.0000
CH	0.014497	0.007202	2.012993	0.0493
GDP	−0.000949	0.003269	−0.290353	0.7727
INDS	0.006849	0.005496	1.246363	0.2182
R-squared	0.974249	Mean dependent var		15.67273
Adjusted R-squared	0.970782	S.D. dependent var		0.284163
S.E. of regression	0.048572	Sum squared resid		0.122683
Long-run variance	0.001800	—	—	—
Model 2: OGHG				
REC	−15.94364	0.664172	−24.00528	0.0000
REO	6.404563	1.196661	5.352029	0.0000
CH	34.24359	4.113123	8.325449	0.0000
GDP	5.955964	1.696273	3.511207	0.0011
INDS	0.688861	3.778139	0.182328	0.8562
R-squared	0.938826	Mean dependent var		69.55666
Adjusted R-squared	0.928867	S.D. dependent var		117.6241
S.E. of regression	31.37128	Sum squared resid		42318.76
Long-run variance	436.5204	—	—	—
Model3: CO2E				
REC	−0.201792	0.015246	−13.23538	0.0000
REO	0.077908	0.020031	3.889301	0.0003
CH	−0.659851	0.097558	−6.763715	0.0000
GDP	−0.100143	0.044285	−2.261350	0.0279
INDS	0.042038	0.074445	0.564686	0.5747
R-squared	0.989037	Mean dependent var		9.987736
Adjusted R-squared	0.987561	S.D. dependent var		6.148272
S.E. of regression	0.685706	Sum squared resid		24.45003
Long-run variance	0.330340	—	—	—

4.2 Results of FMOLS

Results from Models 1, 2 and 3 from Table 8 reveal that FMOLS yield nearly similar results in terms of sign, magnitude, and statistical significance. Combustible renewable and waste "CRW" have a significant negative effect on TGHG, OGGE and CO2E, this result clearly shows that the use of solid biomass, liquid biomass, biogas, industrial waste and municipal waste reduces emissions of air pollutants. This result is consistent with the most recent literature on the catalytic role of biomass energy in reducing air pollution. Indeed, Magazzino et al. (2021) confirmed that biomass energy consumption significantly reduces CO_2 emissions in Germany. Similarly, Bilgili et al. (2016); Bilgili et al. (2017) argued that biomass energy mitigates the level of emissions in the USA.

Alternative and nuclear energy "ANE" has a negative impact on "OGHG" and "CO2E", but an unexpected significant positive effect on "LNTGHG", this surprising result can be explained to our knowledge by the fact that some renewable energy emits greenhouse gases during the production of energy devices. These emissions are much lower than those of fossil fuels.

For the variable "GDP", it has a significant positive effect on the emission of industrial gases (OGHG), an increase in gross domestic product in turn increases the emissions of fluorinated gases: (HFCs; PFCs and SF6). To the best of our knowledge, these results are clearly explained by the economic structure of the mentioned countries, especially China, which is generally based on secondary industry, contributing significantly to air pollutant emissions, China consumed nearly 70% (69.77%) of the secondary industry of its total energy consumption (Lin and

TABLE 11 Moderating effect.

Model 1: LNTGHG				
Variable	Coefficient	Std. Error	t-Statistic	Prob
REC	−0.048993	0.001345	−36.41318	0.0000
REO	0.014178	0.002395	5.919338	0.0000
R_D_REC	0.003982	0.001139	3.496248	0.0010
CH	−0.000814	0.008541	−0.095249	0.9245
GDP	0.001903	0.003611	0.527028	0.6005
INDS	−0.010398	0.006426	−1.618051	0.1118
R-squared	0.978030	Mean dependent var		15.67273
Adjusted R-squared	0.974584	S.D. dependent var		0.284163
S.E. of regression	0.045303	Sum squared resid		0.104668
Long-run variance	0.002048	—	—	—
Model 2: OGHG				
REC	−15.09168	0.820806	−18.38641	0.0000
REO	2.732185	1.701975	1.605302	0.1159
CH	26.09813	4.998152	5.221556	0.0000
GDP	7.450199	1.999752	3.725562	0.0006
INDS	−7.193586	4.551534	−1.580475	0.1215
R_D_REC	2.126534	0.612721	3.470640	0.0012
R-squared	0.944036	Mean dependent var		69.55666
Adjusted R-squared	0.933376	S.D. dependent var		117.6241
S.E. of regression	30.36064	Sum squared resid		38714.27
Long-run variance	552.3678	—	—	—
Model 3: CO2E				
REC	−0.224817	0.004745	−47.37975	0.0000
REO	0.091201	0.026313	3.465932	0.0032
CH	−0.149478	0.062096	−2.407234	0.0285
GDP	−0.033730	0.024421	−1.381153	0.1862
INDS	0.050983	0.023463	2.172885	0.0452
R_D_REC	−0.017088	0.004697	−3.638215	0.0022
R-squared	0.964366	Mean dependent var		4.205910
Adjusted R-squared	0.946548	S.D. dependent var		1.944409
S.E. of regression	0.449540	Sum squared resid		3.233373
Long-run variance	0.010377	—	—	—

Zhu, 2019), with the main energy consumption in China is still fossil fuels (Zhu et al., 2020). Similarly, Germany still relies heavily on fossil fuels (especially coal). This finding is reinforced by the variable Industry (including construction) which has a significant positive effect on the "OGHG". Our result is consistent with the work of Dong et al. (2019), Lin and Zhu (2019) and Zhu et al. (2020).

Our empirical findings support the "Energy security theory". This theory states that rapid technological changes in the energy sector could radically alter future energy prospects, while the shift to renewable energy has positive effects on the climate and the environment.

4.3 Moderating effect

In addition to the direct effect, this study discusses the moderating effect. In accordance with the mentioned assumptions, this paper tests the Research and development activities as a moderating variable; the results are presented in Table 9.

It can be seen from Table 9 that the Research and development activities have played a significant positive moderating effect between RE and Pollution indicators reduction. This shows that after the use of RE, pollution indicators can be decreased; this effect accelerates even further after the integration of research and development. In order to enable such large-scale deployments, continued research and development efforts are required, with an emphasis on economic sustainability (Blaabjerg and Ionel, 2015). Thus, supporting research, development and innovation is one of the key elements of the energy transition to accompany the corresponding sectors towards maturity, competitiveness and the long-term targets of environmental protection.

4.4 Robustness test

To check the robustness of our results, we exploited a robustness analysis. We re-estimate all models using the variable "REC" (Renewable Energy Consumption) as a new measure of RE.

To check the robustness of our results, we exploited a robustness analysis. We re-estimate all models using the variable "REC" (Renewable Energy Consumption) as a new measure of RE. Table 10 presents the results found following the integration of new variables, Renewable energy consumption "REC" has a significant negative effect on air pollutants, which indicates that the increase in "REC" is beneficial for reducing pollution indicators. Our results are similar to those obtained by Ma et al. (2021) who demonstrated a significant reduction in carbon emissions from renewable energy in Germany and France.

Table 11 presents the results found after introducing the moderating effect of the R&D variable. The results using a new measure appear very similar to the original results of the basic model. Thus, the use of renewable energies is perceived as a slowing down of the pollution indicators.

The results of the robustness test prove that there is a significantly negative relationship between the use of renewable energy and the reduction of air pollution, with investment in research and development activities strengthening this negative relationship.

Results from the alternative measure "REC" confirm the robustness of our results.

5 Discussion

Our findings are consistent with previous literature that links renewable energy use with decreases in pollution indicators. Thus, several research studies have shown that the use of renewable energies is very effective in the mitigation of environmental pollution. Renewable energy is one of the solutions to climate change mitigation. The growth of renewable energy yields significant reductions of carbon emissions (Kelly et al., 2019) and overall ecological footprint reduction (Alola et al., 2019). Therefore, the achievement of climate change mitigation requires the promotion of renewable energy consumption. Thus, the continuous increase in energy demand is among the factors that have significantly influenced policy makers to encourage local communities and private sectors to play their role in sustainable energy production. This covers the saturation of human welfare, and the consequent impairment of human health due to environmental pollution (Hung, 2021). For the countries studied, the real problem does not lie in the production of these renewable energies, but really in their uses, taking for example the case of China, although it presents the first producer of these energies, it is currently the largest carbon emitter. This is explained by the low use of these energies. In this context, a better integration of renewable energies in the industrial sector of the countries studied is highly recommended.

While existing works on this topic only deal with the CO_2 variable, we fill the gap in the literature and treat each pollution indicator individually, moving from the general framework ("Total Greenhouse Gas Emissions") to the specific framework ("CO_2 Emissions" and after "Other Greenhouse Gas Emissions" which includes only fluorinated gas emissions (HFCs, PFCs and SF6)). The consumption of renewable energy has very little negative impact on the environment because it does not produce waste or polluting gas emissions. This means that renewable energies offer a global solution because they do not inject polluting gas emissions into the environment. The results suggest the introduction of renewable energies and the support of research and development projects. The development of research and innovation in renewable energies is highly recommended in order to find profitable solutions and benefit from the use of inexhaustible sources such as the sun or the seabed for energy supply. For this reason, Governments around the world must support research and development activities. In addition, dedicated calls for research and innovation projects can also accelerate the development of renewable energies by providing specific support to project developers.

6 Conclusion

Given the growing importance of long-term sustainable goals over short-term goals, as well as the importance of this issue, and since we all know the firm belief that "there is no other Planet B to live on", this paper aims to present the renewable energy practices for the panel of China; USA and Germany, and to determine whether these efforts have contributed to reducing environmental problems and enjoying a clean world. Panel fully modified OLS method showed that the deployment of renewable energies has significantly contributed to the decrease of polluting gas emissions; also, Research and development fully moderate this relationship. The results of the empirical analysis support the research hypotheses, and confirm on the one hand that the use of RE can reduce emissions, and on the other hand that R&D spending reinforces this relationship. For the studied countries, the real problem does not lie in the production of these renewable energies, but really in the right use, taking, for example, the case of China, although it presents the first producer of these energies, it is currently the largest carbon emitter. In this context, better investment in R&D activities is highly recommended.

To enhance energy security and reduce sensitivity to fluctuations in conventional energy prices, we recommend i) digitization of the energy transition so as to equip as many metering points as possible with smart meters and to maximize the use of secured gateways for the implementation of energy transition-related applications; ii) Investing in the most efficient sustainable energy source to reduce environmental pollution in each country, could be a rational policy; iii) Integrate research and development work into the process of energy transition and climate action, to achieve the various long-term energy and climate objectives. And finally, Place energy and climate policy efforts in an international context to achieve long-term goals and ensure the competitiveness of the global economy.

Due to the rise in the involvement of environmental organizations and climate activists, as well as the increasing interest in sustainability goals, corporate social responsibility (CSR), and ESG criteria by various stakeholders, more studies on the importance of innovation and sustainability in the energy sector should be conducted.

Future research could also be expanded for firms in other sensitive sectors for example tourism and transport. An analysis of the differences between socially responsible and non-responsible companies can also be conducted in order to draw further conclusions about the need to be committed to humanity, environment and society.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: https://databank.worldbank.org/reports.aspx?source=world-development-indicators.

Author contributions

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

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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Effects of financial development, FDI and good governance on environmental degradation in the Arab nation: Dose technological innovation matters?

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The motivation of the study is to gauge the impact of financial development, FDI, Technological innovation, and good governance on environmental degradation in the Arab Nation for the period 1991–2019. Several techniques have implemented, including error correction-based cointegration, cross-sectional ARDL, Non-linear ARDL and Heterogeneous causality test for directional causality. The results of Slope of homogeneity, CSD and unit root test following CIPS and CADF, revealed that research variables are exposed with heterogeneity properties, cross-sectionally dependent, and all the variables become stationary after the first difference. The long-run cointegration between explained and explanatory variables established through error correction based cointegrating test. Referring to results derived from CS-ARDL, study exposed financial development has a detrimental effect on environmental sustainability, suggesting the intensification of CO_2 emission and ecological instability. On the other hand, the role of FDI, GG, and TI exposed beneficiary in mitigating the environmental adversity. The asymmetric assessment revealed asymmetric association between explained and core explanatory variables which is valid in the long-run and short-run horizon. Finally, the casual association, study unveiled bidirectional causality between FDI, TI and ED [FDI←→ED; TI←→ED]. On the policy note, the study advocated that environmental improvement through financial channels should be efficiently monitored in the case of credit extension and incorporation with existing environmental policies.

KEYWORDS

environmental degradation, FDI – foreign direct investment, governmental effectiveness, financial development, technological innovation, CS-ARDL, NARDL asymmetric

1 Background of the study

Environmental protection has become an undeniable concern for sustainability due to excessive cost involvement in restoring the ecological imbalance and environmental sustainability. Across the world, a significant challenge faced by many countries due to environmental degradation (ED, hereafter) and its adverse effects on economic fundamentals, including poverty aggravation, dwindle agro-productivity, shrinkage of domestic trade liberalization. Furthermore, pollution produced by industry is often poured into rivers, rendering such rivers unsuitable for other purposes. As a result of these and other forms of environmental degradation, there will be substantial repercussions for the economy and the health and wellbeing of the population. On the other hand, the magnitude of these expenditures is often disregarded since there is no effort to quantify them. As a result of this, it may be difficult for a country to evaluate the scope of the damage done to the environment, much alone take steps to prevent, reduce, or repair the damage.

As far as ED is concerned with overall macro-economic performance, existing literature has posited a one-directional effect that is an adverse linkage with economic growth (Alvarado and Toledo, 2017; Alvarado et al., 2018; Danish et al., 2019), trade openness (Oktavilia and Firmansyah, 2016), FDI (Neequaye and Oladi, 2015), inequality and poverty. On the other hand, referring to the relaxed and ineffective environmentally regulated economy, literature has suggested those economy has found baaven for the foreign investors has less complication for managing the environmental dispute, which entice them for fund mobilization (Kisswani and Zaitouni, 2021). Population haven hypothesis postulated that for some instance developing nations entice FDI with exposed to relax and unregulated environmental concern. It is suggesting that cost of environmental dissertation has neglected for economic process through the contribution of FDI. When it comes to developing nations, promoting sustainable long-term economic development and environmental preservation often conflicts with the need to raise production to expand job opportunities and wages. Because providing for the necessities of people living in developing nations provides a rational basis for the current configuration of the EKC, it is important to be cautious of efforts to reduce CO_2 emissions at the expense of increasing output (JinRu et al., 2022).

The preset study considered financial development (FD, hereafter), foreign direct investment (FDI, hereafter), governmental effectiveness (GG, hereafter), and technological innovation (TI, hereafter) in the equation of environmental degradation. Regarding the nexus between FD-led ED, the existing literature has yet to establish conclusive evidence in explaining the FD effects on ED. However, considering the posted evidence in the literature, two domains of evidence can be exploded. First, the detrimental role of environmental degradation. At the same time, another strand explained the beneficial effects of FD on ED. Environmental economists have long praised FD for its good impact on the planet (Ahmad M. et al., 2022). Literature suggested that FD foster environmental development by supporting credit facilities for industrial operational process efficiencies and technological up gradation. Menegaki et al. (2021) suggested financial development (FD) expand financial services accessibility and improve the existing ones to increase economic growth. Rajan and Zingales (2003) contend that the accumulation of local capital invested in developing locally-based enterprises is a major driver of economic growth. Another line of evidence available by contending the detrimental role of financial development in ED, implying that credit accessibility for the drive for industrial development with neglected the environmental concern, results in environmental degradation. Meanwhile, innovations in the financial sector contribute to the development of sound banking procedures (Musah et al., 2022b; Dai et al., 2022; Rong and Qamruzzaman, 2022). The role of FDI has yet to reveal with a conclusive note, implying the mixed effect available in explaining the nexus between FDI-led ED. A growing number of studies have postulated that a less regulated environmentally focused economy fascinates foreign investors in mobilizing their resources for industrial development with the use of conventional energy. Literature suggested that the inefficient process and fossil energy consumption intensify environmental degradation by injecting excess CO_2 emissions. Concurrently, another domain of findings revealed a positive linkage between FDI and environmental quality, indicating that the inflows of FDI bring technological–know and the efficient operational process and support economy in dragging the degree of CO_2 emission which significantly contributed in improving the environmental quality. Thus receipts of FDI have to be positively guided in terms of environmental protection so that economic sustainability should be the concern.

The motivation of the study is to gauge the impact of financial development, foreign direct investment, good governance and technological innovation on environmental degradation in Arab nations with the application of both symmetric and asymmetric framework.

The present study has contributed to the existing literature in the following ways. First, in terms of empirical nexus targeting environmental degradation with technological innovation. Even though several studies have implemented in documenting the effects of TI on ensuring environmental sustainability, however, referring to Arab nations for TI-led ED has yet to investigate. Thus with our best knowledge for the first time, the nexus between FD, FDI, TI, GG, and ED has been implemented by concentrating a panel of Arab nations. Second, existing literature has investigated the impact of selected explanatory variables with the implementation of a linear framework, but the empirical model estimation with non-linear decomposed variables has opened an alternative thinking process for future policy formulation over conventional and perceived attitudes. Third, the present study has considered both linear and non-linear decomposed units of explanatory variables in evaluating the directional association.

For evaluating the empirical nexus and documenting the elasticity's of explanatory variables on environmental degradation, the study has implemented a slope of homogeneity test, cross-sectional dependency test, panel unit root test following CIPS and CADF and error correction based panel cointegration test. The long-run and short-run coefficients have been documented through CS-ARDL and Non-linear ARDL. Finally, the directional association is exposed by executing the D-H causality test. The study revealed that research units had shared certain common dynamics with heterogeneity properties, and variables were integrated after the first difference. The cointegration test following error correction residual based confirmed the long-run association between explained and explanatory variables. Referring to the long-run and short-run elasticity's extracted from CS-ARDL, it is apparent that financial development has a detrimental effect on environmental sustainability, suggesting the augmentation of CO_2 emission and ecological instability with the credit facilities for industrial progress. At the same time, the coefficients of FDI, GG, and TI have exposed beneficial effects in mitigating environmental adversity. The asymmetric estimation revealed long-run and short-run non-linear effects from explanatory variables to explained variables. Finally, in the directional

TABLE 1 Summary of literature survey: FD-led ED.

Author	Sample (Frequency)	Methodology	Effect	Causality
Ahmad et al. (2022b)	ASEAN regions (2000–2019)	CIPS, CADF, PMG-ARDL	+ve	n/a
Rjoub et al. (2021)	Turkey (1960–2016)	Unit root test, ARDL, FMOLS, DOLS, CCR	+ve	n/a
Ahmad et al. (2022a)	Emerging economies (1984–2017)	CS-ARDL	+ve	FD?ED
Alabi et al. (2021)	Sri Lanka (1971-–2014)	ARDL	+ve	FD?ED
Nawaz et al. (2020)	ASEAN countries (2008–2018)	CIPS and CADF, PMG, DOLS, FMLOS	+ve	n/a
Shahbaz et al. (2020a)	UAE (1975Q1-2016Q4)	structural break and cointegration tests	+ve	FD→CO_2
Ali et al. (2019)	Nigeria (1971–2010)	ARDL	+ve	n/a
Hundie (2018)	Ethiopia (1970–2014)	ARDL	+ve	FD→CO_2
Ali et al. (2015)	Pakistan (last 2 decades as per research published year)	Carbon emission model.	+ve	FD?ED
Xu et al. (2018)	Saudi Arabia (1971–2016)	ARDL, VECM	+ve	FD←→ED
Haseeb et al. (2018)	BRICS countries (1995–2014)	CIPS, CADF, DSUR	+ve	FD←→ED
Asumadu-Sarkodie and Owusu (2016)	Sri Lanka (1971–2012)	ARDL, neutral network	+ve	FD→ED
Wang et al. (2020)	N11 countries (1990–2017)	CIPS, CADF, CCCEMG.	+ve	n/a
Li et al. (2021)	43 BRI regions (1991-2017)	robust mean group,	-ve	n/a
Ahmed et al. (2020)	Pakistan (1996–2018)	ADF, PP, ARDL	-ve	n/a
Khan et al. (2021b)	184 countries worldwide (1990–2017)	SUR, GMM model	-ve	n/a
Salahuddin et al. (2015)	GCC countries (1980–2012)	DOLS, FMLOS, DFE	-ve	≠
Chen et al. (2019)	CEE countries (1980–2016)	DSUR	neutral	≠

investigation, the test statistics exposed bidirectional causality between FDI, TI and ED [FDI←→ED; TI←→ED]. On the policy note, the study advocated that environmental improvement through financial channels should be efficiently monitored in the case of credit extension and incorporation with existing environmental policies.

The rest of the strictures are as follows. Hypothesis development and pertinent literature survey are displayed in Section 2. The variables definition and estimation strategies are displayed in Section 3. Empirical model estimation and interpretation are exhibited in Section 4. Section 5 deals with the findings discussion and the conclusion displayed in Section 6.

2 Literature survey and hypothesis development

2.1 Financial development and environmental degradation/carbon emission

The nexus between financial development and environmental degradation, existing literature posted two vines of linkage between them: causative and deterrent effects on ED. The first vine of empirical literature advocated the catalyst role of FD in aggravating environmental degradation (Nawaz et al., 2020; Alabi et al., 2021; Shahbaz et al., 2020a; Ali et al., 2019; Hundie, 2018; Alam, 2022). For instance, In the case of ASEAN, Ahmad S. et al. (2022) documented that as financial inclusion and development are rising, both in the short and long run, it degrades the environmental quality. As a result, to reduce carbon dioxide emissions as much as possible, climate change adaptation policies must be taken into account along with financial development. In the case of Turkish, Rjoub et al. (2021) explored the nexus of financial development-led ED for1960 from 2016. The study of Ahmad M. et al. (2022) analyzed the effects of financial development and prosperity on the environment and its ecosystem through the human capital system for the emerging economies between 1984 and 2017, and research has unveiled that financial development reduces environmental quality while declining ecological quality, thus the study advises creating awareness of the need to preserve environmental quality by investing in human capital while using financial resources. In the paper of Ali et al. (2015) studies using 2 decades data of developing countries, i.e., Pakistan, to understand environmental degradation for rising financial growth and its development. The research found Pakistani economic expansion and expanding financial development are positively correlated with rising carbon emissions. Wang et al. (2020) analyze the various dimensions of carbon emissions of N11 countries using 1990 to 2017 and revealed a strong correlation between CO_2, economic growth, and GDP. These results would effectively utilize them as a tool to promote more technological innovation and the application of renewable energy sources to achieve desired aims. For details see Table 1.

The second domain of literature advocated the beneficial role in environmental improvement through reassessing the degradation process (Creane et al., 2004; Claessens and Feijen, 2007; Salahuddin et al., 2015; Charfeddine and Kahia, 2019; Khan S. et al., 2021). For instance, Dasgupta et al. (2001) evaluate the nexus between pollution and financial development in developing nations and disclose that with strong environmental regulation, the financial sector has shown respect for environmental control while allowing credit extension in society. The financial sector has offered better environmental quality in the long run by promoting environmental protection and green energy inclusion. In the case of BRI, Li et al. (2021) investigate that the environment is being affected by the rising financial development for the period 1991 to 2017. Study reveals that financial development has a disadvantageous impression on environmental damage and so it is proposed to develop the financial sectors further in order to get more desirable results in the development of the environment. Furthermore, Ahmed et al. (2020) contends that as financial development increases, environmental quality improves and that it is vital to continue financial development to enable a cleaner environment.

However, the neutral association between financial development and environmental degradation, observed in the study of Chen et al. (2019), evaluates the role of financial development on environmental degradation using yearly data from 16 CEE countries from 1980 to 2016. Although other variables examined in this report exhibit substantial relationships, the study's findings indicate that there is no substantial evidence that financial development is damaging the environment. Furthermore, for Saudi Arabia, Xu et al. (2018) for the period 1971 to 2016 highlights neutral association between FD and ED. For the case of BIRCS, Haseeb et al. (2018) assess the effect of financial development on energy consumption, globalization, economic growth, and urbanization using the Environmental Kuznets Curve (EKC) model from 1995 to 2014. Based on this study, there is a bidirectional causal relationship between financial development and carbon dioxide emissions, energy consumption, and economic boom. For Srilanka, Asumadu-Sarkodie and Owusu (2016) addressed the research interest of how financial development impacts environmental decay in Sri Lanka using data from 1971 to 2012.

Hypothesis-1: *Financial development has a detrimental effect on environmental quality.*

2.2 FDI and environmental degradation/ carbon emission

The first domain of literature revealed that FDI has a detrimental effect in establishing the environmental quality (Ahmad et al., 2020; Abdouli and Hammami, 2017; Pazienza, 2015; Baek, 2016; Solarin et al., 2013). For instance, Musah et al. (2022a) analyze the concern of FDI impacting environmental adversities by analyzing data from G20 countries between 1992 and 2018. According to studies, as FDI rises will results in carbon dioxide emissions rise in some countries. In order to lower carbon dioxide emissions, stimulate the local economy, and enhance environmental quality, these findings suggest that green urbanization policies be applied. In the case of Chinese provincial data, Wang et al. (2021) explore the basal system and evidence of how FDI is impacting carbon emission in 30 provinces in major lands in China using panel data ranging from 2004 to 2016. In line with the research, FDI is one of the factors that lead to CO_2 emissions in the specified provinces. On policy note, study advocated the ETS can be used to eliminate CO_2 emissions, but it can't have a large impact on foreign direct investment; hence other policies are also included here to serve as a guide(Ma hmood and Furqan, 2021; Manigandan et al., 2022).

Focusing chines economy, Cai et al. (2021) highlights the outward FDI connected with carbon emission in 30 provinces of China (excluding Tibet, Hong Kong, Macao, and Taiwan) from 2005 to 2016. The study's findings say China's FDI abroad greatly raises carbon dioxide emissions, so the country ought to provide greater incentives for the introduction of IFDL to improve the environment and manage CO_2 emissions. Similar findings can be found in Latief et al. (2021) for SAARC using panel data from 1990 to 2016. In BRICS, Younis et al. (2021) considere a data set from 1993 to 2018. Seker et al. (2015) in the Turkish environment spanning data from 1974 to 2010 and disclose a positive connection between FDI and CO_2 emission, even though it is a minimal effect. To address this problem, FDI should only be supported by the economy's technologically advanced and eco-friendly sectors. Jiang (2015) investigates the effect of flexible FDI on territorial economic expansion on pollution degrading environmental quality using the EKC (Environmental Kuznets Curves) hypothesis across 28 Chinese provinces using data from 1997 to 2012. Findings discloses that FDI contributes to superfluous pollution in the environment, but over time as the economy grows, the emission rate also declines (Ma hmood et al., 2021; Guang-Wen et al., 2022).

Another strands of findings highlight the beneficial role of FDI in achieving environmental sustainability through green energy inclusion, energy efficiency, and technological advancement in the operational process. For example, Mukhtarov et al. (2021) analyze the impact of FDI on CO_2 emissions using data from 1996 to 2013 for Azerbaijan using a time series modeling approach. The research specifies that the impact of FDI was positive prior to 2006 but eventually, after 2006 till 2013, the impact was negative on carbon dioxide discharge, and so there is a diverse effect of FDI on carbon dioxide emission, which has been discussed throughout this paper. Abban et al. (2020) investigate the relationship of FDI with economic growth and energy intensities with carbon dioxide emission in BRI (Belt and Road) countries from 1995 to 2015. Results explain that FDI and CO_2 emissions had a bidirectional causal link across all income categories. The empirical findings also highlight a few crucial measures. Ahmad et al. (2020) inquire about the effect of 29 provinces' Chinese outward FDI on domestic CO_2 emissions using panel data from 2003 to 2016. Following the findings, outside FDI increased environmental pollution due to the scale effect, but by maximizing modern domestic technology and industrial diversification, outward FDI improved environmental quality. The paper makes rational recommendations for the authorities to adopt. Summary survey displayed in Table 2.

Hypothesis-2: *inflows of FDI prompt the environmental sustainability.*

2.3 Institutional quality and environmental degradation

Well-performing institutions foster sustainable economic growth by ensuring equitable development in every corner of

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TABLE 2 Literature summary: FDI-led environmental degradation.

Author	Sample (Frequency)	Methodology	Effect	Causality
Musah et al. (2022a)	G20 countries (1992-2018)	CSARDL	+ve	←→
Wang et al. (2021)	30 provinces in major lands in China (2004-2016)	TREG	+ve	N/A
Cai et al. (2021)	30 provinces of China [excluding Tibet, Hong Kong, Macao, and Taiwan] (2005-2016)	NARDL	+ve	N/A
Latief et al. (2021)	SAARC (1990-2016)	DOLS,VECM	+ve	←→
Younis et al. (2021)	BRICS (1993-2018)	GMM	+ve	n/a
Abban et al. (2020)	BRI countries (1995-2015)	PCT, DH-causality	+ve	←→
Ahmad et al. (2020)	90 belt and road countries (1990-2017)	OLS, DH causality test	+ve	FDI→ED
Abdouli and Hammami (2017)	17 MENA countries (1990-2012)	SVAR	+ve	FDI→ED
Baek (2016)	5 ASEAN countries (1981-2010)	PMG	+ve	n/a
Seker et al. (2015)	Turkey (1974-2010)	Hatemi-J test, ARDL, ECM model	+ve	FDI→CO_2
Jiang (2015)	99 low, medium and high-income economies (1975-2012)	Perpetual inventory method (PIM)	+ve	n/a
Jiang (2015)	28 provinces of China (1997-2012)	Fixed Effect	+ve	n/a
Islam et al. (2021)	Bangladesh (1972-2016)	ARDL	-ve	n/a
Zhang et al. (2020)	30 provincial level administrative (2009-2017)	TREG	-ve	n/a
Ansari et al. (2019)	29 countries (1994-2014)	IPS, FMOLS,	-ve	n/a
Sung et al. (2018)	28 sub-regions of manufacturing divisions of China (2002-2015)	GMM	-ve	n/a
Mukhtarov et al. (2021)	Azerbaijan (1996-2013)	SSTM	-VE	n/a

society. Moreover, institutions established governmental effectiveness, resource reallocation, and environmental protection in the market-based economy. Additionally, individual and social behavior toward society is purely governed by the established rules, laws and regulations, which is the ultimate contribution of effective and efficient institutions (Mahmood, 2022a; Qamruzzaman, 2022a; JinRu and Qamruzzaman, 2022; Xaisongkham and Liu, 2022). Kirkpatrick and Parker (2004) advocate that good governance has a catalyst in economic transition, indicating the promotion of industrialization with the inclusion of environmental protection through lowering the degree of CO_2. The effects of good governance in the process of achieving environmental sustainability can be detected through either direct/or indirect channels. Kha H. et al. (2021) xpress concern about ED by grinding the relationship between environmental parameters relating to institutional quality and technological advancement using panel data from 2002 to 2018. The study unveils several institutional quality factors to account for environmental carbon dioxide emissions. Focusing on developing nations for 1991–2017, Azam et al. (2021) highlight the institutional quality influences carbon dioxide and ethane emissions as it positively impacts energy usage in the context of oil and petroleum product assets, which is influenced by the political steadiness, regulatory constraint, and democratic accountability. Economic globalization has yet to improve natural quality in developing nations. for Emerging Markets and Developing Economies (EMDEs), Le and Ozturk (2020) for the period 1990 and 2014 reveals that as governmental operations induces CO_2 emissions and intensify environmental degradation. Therefore, it is recommended that good governance be ensured while considering other concerns to lessen pollution problems. See Table 4 for details survey.

For the case of Chile, Udemba (2021) discuss the climate change issue using data from 1984 to 2018 and ways to manage ED by forming a nonlin-ear assessment. Asymmetric connection between institutional quality and carbon emission, providing both positive and negative shocks. Results show that institutional quality has negatively impacted carbon emissions, which is vital for addressing the issue of climate change. Furthermore, Khan et al. (2022) investigate environmental degradation and how it is related to the role of good institutional quality in 176 countries collecting data from 1995 to 2015. The study's findings suggest quality institutions are responsible for a quality environment by reducing carbon emissions and pollution, so it is recommended to monitor institutions and other included aspects in a better approach to improve the overall environment. A similar line of findings can be observed in the literature posted in the study of Hussain and Dogan (2021), Haldar and Sethi (2021), Salman et al. (2019), Mahmood (2022b) and Wawrzyniak and Doryń (2020). In the case of the south Asian economy, Zakaria and Bibi (2019) for the period 1984 to 2015 expose that institutional quality has a negative interaction with CO_2 emissions; however, since environmental quality has improved attributable to financial development, the

TABLE 3 Summary literature survey: IQ –led ED.

Author	Sample (Frequency)	Methodology	Effect	Causality
Khan et al. (2021a)	World Bank database (2000-2019)	GMM model	+ve	n/a
Azam et al. (2021)	66 developing countries (1991-2017)	SYS-GMM, GMM, TSLS	+ve	n/a
Le and Ozturk (2020)	47 EMDEs (1990-2014)	CADF and CIPS	+ve	IQ→CO_2
Xaisongkham and Liu (2022)	115 developing nations (2002-2016)	SYS-GMM estimators.	-ve	n/a
Udemba (2021)	Chile (1996Q1 to 2018Q4)	NARDK	-ve	n/a
Khan et al. (2022)	176 countries (1995-2015)	OLS model, GMM model	-ve	n/a
Hussain and Dogan (2021)	BRICS (1992-2016)	ARDL	-ve	n/a
Haldar and Sethi (2021)	39 developing countries (1995-2017)	MG, AMG, CCEMG, GMM, FMOLS,	-ve	n/a
Salman et al. (2019)	East Asian countries (1990-2016)	FMOLS, DOLS, VECM granger causality test	-ve	IQ→Carbon emission
(Wawrzyniak and Doryń, 2020)	93 emerging and developing countries (1995–2014)	GMM estimation	-ve	n/a
Zakaria and Bibi (2019)	South Asia (1984-2015)	2 SLS, GLS.	-ve	n/a
Ibrahim and Law (2016)	40 Sub-Sahara African countries (2000-2010)	GMM estimator, dynamic panel model	-ve	n/a
Ahmed et al. (2020)	Pakistan (1996-2018)	ADF, PP, ARDL, NARDL, ECM	-ve	n/a
Shah et al. (2020)	D-8 countries (1990-2016)	ARDL, FMOLS, DOLS	-ve	IQ→Carbon emission
Samimi et al., 2012	21 MENA countries (2002-2017)	panel data regression analysis	-ve	n/a
Mehmood et al. (2021)	Pakistan, India, Bangladesh (1996Q1-2016Q4	ARDL	indifferent	India, BD: IQ←→CO_2 emission
Egbetokun et al. (2019)	Nigeria (1970-2017)	EKC model	indifferent	n/a

TABLE 4 Summary literature survey: TI-led ED.

Author	Sample (Frequency)	Methodology	Effect	Causality
Adebayo and Kirikkaleli (2021)	Japan (1990Q1-2015Q4)	series of wavelet tools, PWC	+ve	n/a
Villanthenkodath and Mahalik (2022)	India (1990-2018)	ARDL	+ve	n/a
Chen and Lee. (2020)	30 Chinese transportation industries (2001-2016)	SGMM	+ve	n/a
Ullah et al. (2021)	Pakistan (1990-2018)	Linear ARDL model, NARDL	-ve	
Ma et al. (2021)	30 Chinese provinces (1995-2019)	CS-ARDL	-ve	n/a
Chien et al. (2021)	Pakistan (1980-2018)	QARDL	-ve	TI←→ED
Adebayo et al. (2021)	South Korea (1980-2018)	ARDL	-ve	TI→CO_2
Xinmin et al. (2020)	China (1980-2018)	ARDL	-ve	n/a
Ibrahiem (2020)	Egypt (1971-2014)	RDL, FMOLS, DOLS	-ve	TI←ED
Shahbaz et al. (2020b)	China (1984-2018)	DARDL	-ve	TI→ED
Sinha et al. (2020)	N11 countries (1990-2017)	QREG	-ve	IT←→ED
Chen and Lei (2018)	30 global countries (1980-2014)	panel quantile regression	-ve	n/a
Li and Wang (2017)	95 countries (1996-2017)	Quantity model, SBM	-ve	n/a
Chen and Lee (2020)	96 countries (1996-2018)	spatial econometric models	indifferent	n/a
Du et al. (2019)	71 countries (1996-2012)	Panel threshold model	indifferent	TI←→ CO_2

TABLE 5 Results of PCA for FD index construction.

Eigenvalues: (Sum = 4, Average = 1)					
				Cumulative	Cumulative
Number	Value	Difference	Proportion	Value	Proportion
1	2.743507	1.897155	0.6859	2.743507	0.6859
2	0.846353	0.530906	0.2116	3.589860	0.8975
3	0.315447	0.220753	0.0789	3.905306	0.9763
4	0.094694	---	0.0237	4.000000	1.0000
Eigenvectors (loadings):					
Variable	PC 1	PC 2	PC 3	PC 4	
DCP	0.513183	-0.308991	-0.784786	0.158996	
DCF	0.435736	0.729553	0.102453	0.517097	
BM	0.466011	-0.578996	0.594764	0.306355	
BMG	0.574118	0.192459	0.140963	-0.783248	
Ordinary correlations:					
	DCP	DCF	BM	BMG	
DCP	1.000000				
DCF	0.405115	1.000000			
BM	0.664897	0.233807	1.000000		
BMG	0.711292	0.771366	0.643426	1.000000	

technological impact should be given priority to resolving this issue. Ibrahim and Law (2016) investigated SSA from 2000 to 2010 and highlighted that institutional quality has potentially brought down carbon dioxide emissions while promoting environmental quality. The supporting evidence was available in the literature offered by Ahmed et al. (2020), Shah et al. (2020) and (Samimi et al., 2012) for the MENA region, spanning annual data from 2002 to 2007. The study documented that, relying on panel data regression analysis, effective governance improves environmental quality, and necessary policies are also mentioned. However, the neutral effects can be documented in the stud of Mehmood et al. (2021), Alam et al. (2022), and Egbetokun et al. (2019). Table 3 displayed the summary of literature survey.

Hypothesis-3: Governmental effectiveness positively tie to environmental quality.

2.4 Technological innovation and environmental degradation

Technological innovation (TI) is crucial for reducing emissions and helping to preserve energy. Moreover, TI is crucial to use both traditional and RE energy sources effectively. New forms of renewable energy (RE) may also be easier to produce with the help of TI. The potential for RE supply to fulfill future energy demand has been increased due to technological advancements that have increased RE capacity. It stands to reason that RE, as a renewable and non-polluting energy source, will grow significantly as the world's energy demands continue to increase. We found a treasure trove of information about the effect of renewable energy on air quality. Most research has shown that increasing the amount of renewable energy used in the total energy mix is the most effective way to reduce carbon dioxide emissions. Technological integration assists in environmental improvement through the reduction of carbon intensity with operational efficiency (Ullah et al., 2021; Ma et al., 2021; Chien et al., 2021; Adebayo et al., 2021; Chen and Lei, 2018; Li and Wang, 2017). It has been proven that the purpose of carbon offsetting may be supported by higher energy expenditures, technical innovation, renewable energy use, research and development investment, and tax payments on carbon emissions. Those who require a citation: in the case of chins economy, Xinmin et al. (2020) assess TI-led ED for the period 1990 to 2018. The marginal effects suggest that trade openness and technological progress reduce CO_2 emissions; however, in the Chinese scenario, technology adoption and GDP augment carbon dioxide emissions. Lag periods of TI are strongly related to CO_2. Consequently, a rise in technological innovation will assist in lowering carbon dioxide emissions. A similar line of association was posted in the literature by Ibrahiem (2020) in Egypt, taking data from 1971 to 2014. Shahbaz et al. (2020b) for China's carbon emissions using time series data from 1984 to 2018. For the case of N11 nations, Sinha et al. (2020) discovered that technological advancement in the direction of the Sustainable Development Goals was the key engine of sustainable environmental development.

The study of Adebayo and Kirikkaleli (2021) sheds additional insight on the relationship between CO_2 technical advancements, renewable energy, and carbon dioxide emissions in Japanese innovation and globalization through wavelet statistical

TABLE 6 Variables proxies.

Variables	Notation	Units	Sources
Environmental degradation			
Carbon emission	CO_2	Metric tons per capita	WDI
Ecological footprint	EF	gha per person	(Network, 2019)
Foreign direct investment	FDI	Inflows of FDI as a % GDP	WDI
Good governance	GG	Governmental effectiveness	WGI
Technological innovation	TI	No patents application, residents	WDI
Financial development index by applying PCA			
Domestic credit to private sector % of GDP	DCP	%	IFS(IMF)
Domestic credit by financial institutions % of GDP	DCF	%	
Broad Money	BM	%	
Growth of Broad Money	BMG	%	IFS(IMF)

techniques using a database that spans the years 1990 to 2015. According to empirical wavelet analysis results, Japan's CO_2 emissions are rising due to globalization, GDP growth, and technological advancements. Another study conducted by Villanthenkodath and Mahalik (2022) assess the correlations between technological advancement and environmental quality in India using annual data from 1980 to 2018. The results show that, when considering how carbon dioxide emissions work, technological advancement and economic boom negatively impact India's environmental quality over time through increasing CO_2 emissions. Chen and Lee (2020) seek to confirm the impact of the technology-environmental innovation indicator system on the carbon dioxide emissions of 30 Chinese transportation industries by decoupling elasticity and econometric models spanning data from 2001 to 2016. The most substantial effect on the transportation sector's CO_2 emissions is made through technological innovation. In a study, Chen and Lee (2020) postulate that TI works more to reduce pollution in countries with higher levels of globalization. Hence, environmental protection awareness in social globalization should get more attention. Du et al. (2019) discover that innovations in green technology do not considerably reduce CO_2 emissions for economies with income levels below the threshold. In contrast, they have a considerable mitigation effect for those with income above the threshold. Details summary literature displayed in Table 4

Hypothesis-4: Ethnological innovation fosters the process of environmental development.

3 Data, theoretical specification and estimation strategy

3.1 Variables definition

The present study intends to assess the effects of financial development, FDI, governmental effectiveness and technological innovation on Environmental degradation in Arab countries 1. A panel of 21 (Twenty-one) countries has been considered for empirical assessment.

As an explained variable, environmental degradation is measured by carbon emission and ecological footprint following the existing literature (Kha H et al., 2021; Gao et al., 2021; Shahbaz et al., 2021; Ansari, 2022). On the other hand, explanatory variables include financial development, which is proxied by the construction of FD through the execution of PAC. Financial development is the second explanatory variable measured by the financial development Index. Existing literature has posted two lines of proxies in documenting the FD in the equation: using single variables and considering the index with implementing PCA (Musah et al., 2022b). In this study, we follow the second line of evidence that the FD Indexed has constructed through the implementation of PCA and the results displayed in Table 5

FDI is measured by the inflows of inward FDI as a percentage of GDP, governmental effectiveness proxies by the governmental effectiveness, which is extracted from WGI, and finally, the no of the patent application measures the technological innovation by residents. The definition and proxies of explained and explanatory variables have posted in Table 6.

3.1.1 Empirical equation

Based on the theoretical construction and existing literature focusing the environmental degradation, we posted the general equation as follows:

$$ED_{CO2} \int FD_{i,t}, FDI_{i,t}, GG_{i,t}, TI_{t,t} \tag{1a}$$

$$ED_{EF} \int FD_{i,t}, FDI_{i,t}, GG_{i,t}, TI_{t,t} \tag{1b}$$

Where ED, EF, CO_2. FD, FDI, GG, and TI denotes environmental degradation, financial development, foreign direct investment, good governance and technological innovation. All the research variables are transformed into natural logarithms and reproduced in the regression format in the following manner.

$$ln\,ED_{CO2,it} = \alpha_0 + \gamma_1 lnFD_{it} + \gamma_2 lnFDI_{it} + \gamma_3 lnGG_{it} + \gamma_4 lnTI_{it} + \varepsilon_{it} \quad (2a)$$

$$ln\,ED_{EF,it} = \alpha_0 + \beta_1 lnFD_{it} + \beta_2 lnFDI_{it} + \beta_3 lnGG_{it} + \beta_4 lnTI_{it} + \varepsilon_{it} \quad (2b)$$

Where the coefficients of $\gamma_1\, to\, \gamma_4$ explain the elasticities of explanatory variables on EF, which CO_2 measures, and the coefficients of $\beta_1\, to\, \beta_4$ denotes the impact on EF, which is proxied by ecological footprint.

3.2 Estimation strategy

3.2.1 Cross-sectional dependency and slope of homogeneity test

The section on appropriate econometric techniques significantly relies on the research unit's inherent attributes, and the conventional techniques are incapacity of handling the heterogeneity and cross-sectional dependency. Thus, we implemented CSDT following Pesaran (2004), Pesaran (2006), and Pesaran et al. (2008); for test statistics, the following equations have been executed accordingly.

$$LM = T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{IJ} \underset{d}{\rightarrow} X^2 N(N+1)2 \quad (3)$$

$$CD_{lm} = \sqrt{\frac{N}{N(N-1)}}\sum_{I=1}^{N-1}\sum_{J=i+1}^{N}\left(T\hat{\rho}_{ij} - 1\right) \quad (4)$$

$$CD_{lm} = \sqrt{\frac{2T}{N(N-1)}}\sum_{I=1}^{N-1}\sum_{J=i+1}^{N}\left(\hat{\rho}_{ij}\right) \quad (5)$$

$$CD_{lm} = \sqrt{\frac{2}{N(N-1)}}\sum_{I=1}^{N-1}\sum_{J=i+1}^{N}\left(\frac{(T-K)\hat{\rho}_{ij}^2 - u_{Tij}}{v_{Tij}^2}\right)(N,0) \quad (6)$$

3.2.2 Panel unit root test

Second-generation panel unit root tests have implemented over conventional ones due to the capacity to address the CSD issue in documenting the variables' order of integration. For stationary tests, we implemented the framework offered by Pesaran (2007), widely known as CIPS and CADF. The test statistic for the null hypothesis test is to be derived by executing the following equation.

$$\Delta Y_{it} = \beta_i + \gamma_i y_{i,t-1} + \pi_i \bar{y}_{t-1} + \beta_i \bar{y}_t + \rho_{it} \quad (7)$$

$$\Delta Y_{it} = \mu_i + \gamma_i y_{i,t-1} + \pi_i \bar{y}_{t-1} + \sum_{k=1}^{p}\beta_{ik}\Delta y_{i,k-1} + \sum_{k=0}^{p}\beta_{ik}\overline{\Delta y}_{i,k-0} + \alpha_{it} \quad (8)$$

$$CIPS = N^{-1}\sum_{i-1}^{N}\partial_i(N,T) \quad (9)$$

Where the parameter $\partial_i(N,T)$ explain the test statistics of CADF, which can be replaced in the following manner:

$$CIPS = N^{-1}\sum_{i-1}^{N}CADF \quad (10)$$

3.2.3 Panel cointegration test

Before implementing the target model for exploring the vectors of explanatory variables on explained variables, we focused on assessing the possible long-run association between ED, FDI, FD, GG and TI. For long-run cointegration, we follow the novel PCT introduced by Westerlund (2007), which can absorb the CSD and SHT and offer efficient estimation. The following equation is to be implemented for long-run cointegration.

$$\Delta Z_{it} = \beta_i' d_i + \rho_i\left(Z_{i,t-1} - \beta_i' W_{i,t-1}\right) + \sum_{r=1}^{p}\gamma_{i,r}\Delta Z_{i,t-r} + \sum_{r=0}^{p}\zeta_{i,j}\Delta W_{i,t-r} + \epsilon_{i,t} \quad (11)$$

The WECPCT has produced two groups of statistics consisting of test statistics for group statistics, i.e., $G_T\,\&\,G_\alpha$ and panel statistics, i.e., $P_T\,\&\,P_\alpha$, which can be extracted by executing the following equation.

$$G_T = \frac{1}{N}\sum_{i-1}^{N}\frac{\zeta_i}{SE\zeta_i};\, G_a = \frac{1}{N}\sum_{i-1}^{N}\frac{T\zeta_i}{\zeta_i(1)} \quad (12)$$

$$P_T = \frac{\zeta_i}{SE\zeta_i};\, P_a = T\zeta_i \quad (13)$$

3.2.4 CSARDL

Considering the results of CDST and SHT, the present study intends to adopt efficient and robust techniques for elasticity's documentation and, most importantly, produce unbiased estimation in the presence of cross-sectional dependency and heterogenetic attributes in the research units. The present study has implemented the target model following the framework familiarized by Chudik and Pesaran (2015), commonly known as CSARDL. The above Eqs 2a, 2b can be reproduced in the following manner.

$$\begin{aligned} ln\,ED_{CO2,it} = \alpha_0 &+ \sum\nolimits_{j=1}^{q1j}\gamma_{ij}\, lnED_{CO2,i\,(t-j)} + \sum_{j=0}^{q}\gamma_{1j} lnFD_{i\,(t-j)} \\ &+ \sum_{j=0}^{q}\gamma_{2j} lnFDI_{it-j} + \sum_{j=0}^{q}\gamma_{3j} lnGG_{it-j} + \sum_{j=0}^{q}\gamma_{4j} lnTI_{it} \\ &+ \sum\nolimits_{j=1}^{q1j}\theta_{1j}\, ln\overline{ED}_{CO2,i\,(t-j)} + \sum_{j=0}^{q}\theta_{1j}\overline{lnFD}_{(t-j)} \\ &+ \sum_{j=0}^{q}\theta_{2j}\overline{lnFDI}_{t-j} + \sum_{j=0}^{q}\theta_{3j}\overline{lnGG}_{t-j} + \sum_{j=0}^{q}\theta_{4j}\overline{lnTI}_{t} + \varepsilon_{it-j} \end{aligned} \quad (14)$$

$$\begin{aligned} ln\,ED_{EF,it} = \alpha_0 &+ \sum\nolimits_{j=1}^{q1j}\beta_{ij}\, lnED_{EF,i\,(t-j)} + \sum_{j=0}^{q}\beta_{1j} lnFD_{i\,(t-j)} \\ &+ \sum_{j=0}^{q}\beta_{2j} lnFDI_{it-j} + \sum_{j=0}^{q}\beta_{3j} lnGG_{it-j} + \sum_{j=0}^{q}\beta_{4j} lnTI_{it} \\ &+ \sum\nolimits_{j=1}^{q1j}\pi_{1j}\, ln\overline{ED}_{EF,i\,(t-j)} + \sum_{j=0}^{q}\pi_{1j}\overline{lnFD}_{(t-j)} \\ &+ \sum_{j=0}^{q}\pi_{2j}\overline{lnFDI}_{t-j} + \sum_{j=0}^{q}\pi_{3j}\overline{lnGG}_{t-j} + \sum_{j=0}^{q}\pi_{4j}\overline{lnTI}_{t} + \varepsilon_{it-j} \end{aligned} \quad (15)$$

Where $\overline{co2}$, $\overline{FD}$, $\overline{FDI}, \overline{GG}, \overline{TI}$ Exhibits the CSA of explained and explanatory variables, α_0, γ_{ij} and β_{ij} explained, $\theta_{1j}\ldots.\theta_{5j}$; $\pi_{1j}\ldots.\pi_{5j}$ denotes the coefficients of CSA of explanatory variables on explained variables.

TABLE 7 Results of CST and SHT.

	LM_{BP}	LM_{PS}	LM_{adj}	CD_{ps}	Δ	Adj.Δ
lnED	338.835***	40.963***	224.227***	30.193***	78.079***	143.519***
lnEF	160.829***	23.219***	218.891***	35.166***	21.362***	101.676***
lnFD	423.004***	16.036***	156.357***	32.469***	57.201***	93.926***
lnFDI	370.056***	32.27***	245.438***	22.839***	18.862***	113.27***
lnGG	370.743***	34.894***	242.281***	21.371***	62.072***	113.044***
lnTI	205.907***	25.987***	168.972***	40.509***	81.547***	136.7***

TABLE 8 Results of PURT.

	At level		Δ	
	CIPS	CADF	CIPS	CADF
lnED	−2.088	−2.738	−6.583***	−7.162***
lnEF	−1.143	−2.047	−6.69***	−6.016***
lnFD	−1.999	−2.602	−4.626***	−2.885***
lnFDI	−1.05	−1.835	−5.292***	−3.282***
lnGG	−1.048	−2.882	−2.681***	−3.757***
lnTI	−1.002	−2.728	−5.353***	−6.298***

TABLE 9 Results of PCT.

Model	ED--->FD	ED--->FDI	ED--->GG	ED--->TI
Gt	−13.478***	−11.451***	−9.53***	−12.708***
Ga	−11.78***	−7.45***	−10.527***	−6.989***
Pt	−10.581***	−13.013***	−11.232***	−5.06***
Pa	−10.772***	−13.899***	−15.391***	−6.579***
KRCPT				
MDF	5.999***	−7.24***	−6.459***	−6.452***
DF	16.156***	15.914***	−6.26***	5.901***
ADF	14.025***	11.988***	21.783***	9.412***
UMDF	2.349***	−7.953***	17.703***	21.699***
UDF	5.989***	−0.551***	−7.275***	4.956***
PCT				
MDF	13.714***	7.112***	11.374***	15.11***
PP	6.928***	4.968***	3.526***	−5.893***
ADF	9.672***	8.89***	11.403***	8.751***

TABLE 10 Results of CSARDL.

	[1]			[2]		
	Coefficient	t-stat	std. error	Coefficient	t-stat	std. error
Panel A: long-run coefficients						
FD	0.1471	0.0073	20.1506	0.1184	0.0089	13.3033
FDI	−0.0875	0.0042	20.8333	−0.1058	0.009	11.7555
GG	−0.1031	0.0099	10.4141	−0.1593	0.0107	−14.8878
TI	−0.1755	0.0069	25.4347	−0.1469	0.0042	−34.9761
c	0.1731	0.0107	16.1775	0.0829	0.0091	9.1098
Panel –B: Short-run coefficients						
FD	0.0628	0.0021	29.9047	0.0314	0.0021	14.9523
FDI	−0.0221	0.0068	−3.25	−0.0197	0.0116	−1.6982
GG	−0.0268	0.0054	4.074	−0.0550	0.0036	15.2777
TI	−0.0159	0.0079	2.01645	−0.0734	0.0046	15.9565
ECT(−1)	−0.1754	0.004	−43.85	−0.0577	0.0106	−5.4433
Panel C: Diagnostic test						
CD test		0.02048			0.025573	
Wooldridge Test for Autocorrelation		0.126062			0.838015	
Normality test		0.266592			0.546674	
Ramsey RESET test		0.016541			0.403379	

3.2.5 Asymmetric ARDL

In recent literature, a growing number of studies has extensively employed the nonlin-ear framework familiarized by Shin et al. (2014) for documenting the asymmetric coefficients that are positive and negative series of explanatory variables on explained variables (Qamruzzaman and Jianguo, 2020; Yang et al., 2021; Mensah and Abdul-Mumuni, 2022; Qamruzzaman et al., 2022). Considering the economic stricture and globalization effects on the economy, we purposively constructed and implemented the following asymmetric equation for exploring the asymmetric effects of explanatory variables, which is $FD^{+} \& FD^{-}, FDI^{+} \& FDI^{-}, GG^{+} \& GG^{-}, TI^{+} \& TI^{-}$.

$$\begin{aligned}\Delta ED_{CO2,it} = {} & \beta_{0i} + \gamma_{1i} ED_{CO2,it-1} + \gamma_{2i}^{+} FD_{t-1}^{+} + \gamma_{2i}^{-} FD_{t-1}^{-} + \gamma_{3t}^{+} FDI_{t-1}^{+} \\ & + \gamma_{3t}^{-} FDI_{t-1}^{-} + \gamma_{4t}^{+} GG_{t-1}^{+} + \gamma_{4t}^{-} GG_{t-1}^{-} + \gamma_{5t}^{-} TI_{t-1}^{-} \\ & + \sum_{J=1}^{Q-1} \gamma_{ij} \Delta ED_{CO2i,t-J} + \sum_{J=0}^{Q-1} \left(\rho_{ij}^{+} \Delta FD_{i,t-j}^{+} + \rho_{ij}^{-} \Delta FD_{i,t-j}^{-}\right) \\ & + \sum_{J=0}^{Q-1} \left(\left(\beta_{ij}^{+} \Delta FDI_{i,t-j}^{+} + \beta_{ij}^{-} \Delta FDI_{i,t-j}^{-}\right)\right) \\ & + \sum_{J=0}^{Q-1} \left(\xi_{ij}^{+} \Delta GG_{i,t-j}^{+} + \xi_{ij}^{-} \Delta GG_{i,t-j}^{-}\right) \\ & + \sum_{J=0}^{Q-1} \left(\pi_{ij}^{+} \Delta TI_{i,t-j}^{+} + \pi_{ij}^{-} \Delta TI_{i,t-j}^{-}\right) + \varepsilon it \end{aligned} \tag{16}$$

$$\begin{aligned}\Delta ED_{EF,it} = {} & \beta_{0i} + \gamma_{1i} ED_{EF,it-1} + \gamma_{2i}^{+} FD_{t-1}^{+} + \gamma_{2i}^{-} FD_{t-1}^{-} + \gamma_{3t}^{+} FDI_{t-1}^{+} \\ & + \gamma_{3t}^{-} FDI_{t-1}^{-} + \gamma_{4t}^{+} GG_{t-1}^{+} + \gamma_{4t}^{-} GG_{t-1}^{-} + \gamma_{5t}^{-} TI_{t-1}^{-} \\ & + \sum_{J=1}^{Q-1} \gamma_{ij} \Delta ED_{EF,t-J} + \sum_{J=0}^{Q-1} \left(\rho_{ij}^{+} \Delta FD_{i,t-j}^{+} + \rho_{ij}^{-} \Delta FD_{i,t-j}^{-}\right) \\ & + \sum_{J=0}^{Q-1} \left(\left(\beta_{ij}^{+} \Delta FDI_{i,t-j}^{+} + \beta_{ij}^{-} \Delta FDI_{i,t-j}^{-}\right)\right) \\ & + \sum_{J=0}^{Q-1} \left(\xi_{ij}^{+} \Delta GG_{i,t-j}^{+} + \xi_{ij}^{-} \Delta GG_{i,t-j}^{-}\right) \\ & + \sum_{J=0}^{Q-1} \left(\pi_{ij}^{+} \Delta TI_{i,t-j}^{+} + \pi_{ij}^{-} \Delta TI_{i,t-j}^{-}\right) + \varepsilon it \end{aligned} \tag{17}$$

The positive and negative series can be derived by implementing the following equations.

$$\left\{\begin{aligned} FD_i^{+} &= \sum_{X=1}^{t} \Delta FD_{ik}^{+} = \sum_{X=1}^{Y} MAX\left(\Delta RE_{iX}, 0\right) \\ FD_i^{-} &= \sum_{k=1}^{t} \Delta RE_{iX}^{-} = \sum_{X=1}^{T} MIN\left(\Delta RE_{iX}, 0\right) \end{aligned}\right. ;$$

$$\left\{\begin{aligned} FDI_i^{+} &= \sum_{X=1}^{t} \Delta FDI_{iX}^{+} = \sum_{K=1}^{Y} MAX\left(\Delta FDI_{iX}, 0\right) \\ FDI_i^{-} &= \sum_{X=1}^{t} \Delta FDI_{iX}^{-} = \sum_{X=1}^{T} MIN\left(\Delta FDI_{iX}, 0\right) \end{aligned}\right.$$

TABLE 11 Asymmetric assessment: ED| $FD^{+/-}$, $FDI^{+/-}$, $GG^{+/-}$, $TI^{+/-}$.

	[3]			[4]		
Variables	Coefficient	St.Error	t-stat	Coefficient	St.Error	t-stat
Panel –A: Long-run coefficients						
FD^{+}	0.2583	0.0151	17.221	0.1811	0.0429	4.2214452
FD	0.2571	0.0122	21.0738	0.1562	0.0508	3.0748031
FDI^{+}	−0.1892	0.0339	−5.58112	−0.1964	0.0677	−2.901034
FDI	−0.1769	0.0447	−3.95749	−0.2076	0.0402	−5.1641791
GG^{+}	−0.1622	0.0358	−4.53073	−0.1393	0.0287	−4.8536585
GG	−0.1645	0.0291	−5.65292	−0.1653	0.0515	−3.2097087
TI^{+}	−0.2611	0.0656	−3.98018	−0.1715	0.0672	−2.5520833
TI	−0.1902	0.0145	−13.1172	−0.1588	0.0687	−2.3114993
C	0.1821	0.0857	2.12485	0.1773	0.0388	4.5695876
Panel –B: Short-run coefficients						
FD^{+}	0.0998	0.018	5.54444	0.1265	0.0632	2.0015
FD	0.0928	0.0094	9.87234	0.1018	0.0859	1.1850
FDI^{+}	−0.0656	0.0096	−6.83333	−0.0637	0.0704	−0.9048
FDI	−0.1024	0.0667	−1.53523	−0.1113	0.0559	−1.9910
GG^{+}	−0.0924	0.0779	1.18614	−0.0641	0.0389	−1.6478
GG	−0.0925	0.0649	1.42527	−0.1138	0.0594	−1.9158
TI^{+}	−0.0771	0.0093	8.29032	−0.068	0.0708	−0.9604
TI^{-}	−0.0839	0.0586	1.43174	−0.0946	0.0232	−4.0775
cointEq (-1)	0.0968	0.0297	3.25926	0.0571	0.0585	0.9760
Panel –C: Diagnostic test						
W_{LR}^{FD}	10.715			11.062		
W_{SR}^{FD}	9.956			11.309		
W_{LR}^{FDI}	13.805			12.588		
W_{SR}^{FDI}	9.251			14.474		
W_{LR}^{GG}	9.659			13.925		
W_{SR}^{GG}	9.971			10.203		
W_{LR}^{TI}	10.098			13.168		
W_{SR}^{TI}	12.811			9.104		

TABLE 12 Results of AMG and CEEMG.

	[5]		[6]	
FD	0.0148(0.004)[3.02]	0.033(0.01)[3.173]	0.0498(0.01)[4.742]	0.0637(0.01)[5.953]
FDI	0.0118(0.006)[1.966]	0.1075(0. 003)[35.833]	0.0444(0.002)[15.31]	0.1015(0.005)[17.203]
GG	0.0167(0. 009)[1.835]	0.0177(0.004)[4.425]	0.0946(0. 008)[11.825]	0.1161(0. 004)[23.693]
TI	0.0828(0. 009)[8.625]	0.1214(0. 011)[10.465]	0.1265(0. 003)[33.289]	0.0974(0.007)[13.342]
C	0.0238(0.011)[2.106]	0.0738(0.004)[16.4]	0.039(0.011)[3.362]	0.0695(0.009)[7.164]
Wald test	0.0112	0.0029	0.003	0.0054
CD test	0.0059	0.0089	0.009	0.0063

$$\begin{cases} \begin{cases} GG_t^+ = \sum_{k=1}^{t} \Delta GG_{iX}^+ = \sum_{X=1}^{Y} MAX\,(\Delta GG_{iX}, 0) \\ GG_t^- = \sum_{X=1}^{t} \Delta GG_{iX}^- = \sum_{X=1}^{T} MIN\,(\Delta GG_{iX}, 0) \end{cases} ; \\ \begin{cases} TI_t^+ = \sum_{X=1}^{t} \Delta TI_{iX}^+ = \sum_{X=1}^{Y} MAX\,(\Delta TI_{iX}, 0) \\ TI_t^- = \sum_{X=1}^{t} \Delta TI_{iX}^- = \sum_{X=1}^{T} MIN\,(\Delta TI_{iX}, 0) \end{cases} \end{cases}$$

4 Estimation and interpretation

Before executing the target equation, the selected research variables passed through several elementary assessment in documenting the inherent properties such as cross-sectional dynamic and homogeneity. The results of CDST and SHT are displayed in Table 7. Referring to test statistics derived from CDST, it is revealed that selected variables have shared certain common dynamics, implying research variables are cross-sectional dependent. At the same time, the test statistics derived from SHT for establishing the heterogeneity with the null hypothesis of homogeneity. SHT rejects the null hypothesis and confirms the heterogeneity attributed.

Next, considering the results of the CDST, study moves in assessing the variables' order of integration by employing the Panel Unit root test (PURT) by following CIPS and CADF. The results of PURT exhibited in Table 8. The test statistics exported from CIPS and CADF exhibit the rejection of the null hypothesis of unit root with the first difference operation, alternatively indicating that the variables become stationary after the first difference.

Table 9 exhibits the test statistics for assessing the long-run cointegration by employing Westerlund (2007) error correction-based cointegration (WECCT). The test group statistics are in Gt and Ga, and the panel statistics are in Pt and Pa, respectively. In terms of statistical significance, it is found that all the test statistics are statistically significant at a 1% level, implying a stable long-run cointegration in Eqs 1, 2. Moreover, the robustness test with Kao and padroni cointegration exposed similar conclusions found in WECCT. Once the long-run association has established, we concentrates on exploring the cointegration vector of explanatory variables in the long and short run.

4.1 Long-run and short-run coefficient: CSARDL

Following, the empirical equation formulated following Chudik and Pesaran (2015) in revealing the long-run and short-run coefficients. The exported coefficients displayed in Table 10 which includes the long-run coefficients in Panel –A the short-run coefficient in Panel –B and the symmetry and residual diagnostic test in Panel –C respectively. Furthermore, the results displayed in column [1] with ED proxied by carbon emission and in column [2], where ED is measured by ecological footprint. The key findings are as follows.

First, the coefficients of financial development revealed a positive connection with environmental degradation in both model estimations in the long run (short-run). Study findings are suggesting that credit accessibility in the economy has detrimental effects on the environment. Our findings are supported by the existing literature but confront the finding posted by Creane et al. (2004) and Claessens and Feijen (2007). In the long run, 0.1471% of excess carbon emissions and 0.1184% of ecological degradation can be intensified due to credit accessibility in the economy for industrial development. Additionally, in the short run, the environmental degradation in terms of carbon emission and ecological depreciation can be exaggerated by 0.0628% and 0.0314% with a 1% changes in financial development. Study findings are advocating the credit facilities in the financial system for industrial and energy development without environmental protection support the economic progress with a cost of environmental degradation.

Second, a contributing effect of FDI in ensuring environmental sustainability has documented that is the reduction of carbon emissions in the environment and ecological justification can be attained with the presence of technological advancement which is one the underlying benefits of FDI receipts, especially in the long run. Particularly, an adverse linkage was revealed between inflows of FDI and carbon emission (a coefficient of −0.0875) and ecological footprint (a coefficient of −0.1593). More precisely, a 1% acceleration in FDI inflows will amplify environmental

TABLE 13 DH-causality test.

Null Hypothesis:	W-Stat.	Zbar-Stat.		W-Stat.	Zbar-Stat.	
	ED measures by Carbon emission			ED measures by ecological footprint		
FDI →ED	4.0807	4.3011	FDI←→ED	1.6269	1.71485	FDI←→EF
ED→FDI	5.5812	5.8826		4.2848	4.5161	
ED→FD	3.8044	4.0099	FD←→ED	2.8873	3.0432	FD←→EF
FD→FD	5.2837	5.5690		1.4261	1.5031	
ED→GG	1.1551	1.2175	GG→ED	1.7311	1.8246	ED→GG
GG→FD	4.8541	5.11zz		1.1742	1.2376	
ED→GG	4.2167	4.4444	ED→CE	5.8894	6.2075	ED→CE
GG→FD	1.1349	1.1962		0.9808	1.033	

TABLE 14 Results of asymmetric DH causality test.

Null Hypothesis:	W-Stat.	Zbar-Stat.		W-Stat.	Zbar-Stat.	
ED measures by Carbon emission				ED measures by ecological footprint		
FDI^{+} ≠→ED	2.6291	2.7710**	ED←→ FDI^{+}	4.2244	4.4523***	FDI^{+} →ED
ED≠→FDI^{+}	5.2518	5.5354***		1.5961	1.6828	
FDI^{-} ≠→ED	1.4569	1.5356	ED← FDI^{-}	4.8002	5.0594***	ED←→ FDI^{-}
ED→FDI^{-}	5.6386	5.9431***		4.7502	5.0067***	
FD^{+} ≠→ED	4.3889	4.6259***	ED←→ FD^{+}	5.4718	5.7673***	ED←→ FD^{+}
ED≠→FD^{+}	4.4388	4.6785***		2.3315	2.4574**	
FD^{-} ≠→ED	1.3230	1.3945	ED→ FD^{-}	4.9532	5.2207***	ED←→ FD^{-}
ED≠→FD^{-}	3.1880	3.3602**		2.4017	2.5313***	
GG^{+} ≠→ED	1.5632	1.6476	ED→ GG^{+}	5.2019	5.4828***	$GG^{+} -\rightarrow ED$
ED≠→GG^{+}	5.7778	6.0899***		1.4388	1.5165	
GG^{-} ≠→ED	5.5185	5.8166***	ED←→ GG^{-}	1.9723	2.0788*	ED→ GG^{-}
ED≠→GG^{--}	4.3613	4.5968***		4.6546	4.9059***	
TI^{+} ≠→ED	3.9362	4.1487***	ED←→ TI^{+}	5.8374	6.1526***	$TI^{+} -\rightarrow ED$
ED≠→TI^{+}	3.3730	3.55515**		1.3262	1.3978	
TI^{-} ≠→ED	2.6652	2.809173*	ED←→ TI^{-}	1.3985	1.4740	$TI^{-} -\rightarrow ED$
ED≠→TI^{-}	2.6089	2.7498*		4.0053	4.2216***	

Note: "←→ Furthermore, → indicates the bidirectional and unidirectional association.

sustainability by controlling CO_2 emission by 0.0875% and ecological correction by 0.1593%. In the short-run, the elasticity's of FDI unveiled positively associated with environmental quality, that is, reduction of CO_2 (a coefficient of 0.0221) and ecological footprint (a coefficient of 0.0197). Our findings are supported by the literature (Sabir et al., 2020) but stand against the literature offered by Shahbaz et al. (2018). In terms of coefficients of inflows of FDI advocated that the transfer of technological know-how in the host economy support energy efficiency and operational development, at large assist in lowering the GO2 emission intensity.

Third, a positive nexus is disclosed between good governance and ED, proposing that good governance increases the society's environmental awareness and induces a lower degree of CO_2 emission and ecological correction. The beneficiary role of GG on ED has been supported by empirical studies (Samimi et al., 2012; Omri and Ben Mabrouk, 2020). Expressly, a 1% change in GG results in improved environmental quality by lowering the carbon emission by −0.1031% and ecological footprint by −0.1593% in the long run. Furthermore, in the short-run, the ED has controlled through CO_2 emission contraction by −0.0268% and ecological footprint by −0.0550%. In terms of GG elasticity in the long-run and short-run assessment, it is apparent that the beneficial role of GG on environmental advancement is more obvious in the long run in comparison to the short-run. The possible reason is that good governance ensures socioeconomic stability by effectively enforcing overall social and economic protection, including environmental degradation, eventually inducing quality of the environment.

Fourth, technological innovation uplifts the environmental quality enhancement, implying that environmental degradation has a negative tie with technological innovation. Inferring the coefficients of TI in the long run (short-run), it is apparent that the present state of environmental status can be improved by lowering the CO_2 injection in the ecosystem and ecological footprint. In particular, a 1% change in IT will improve environmental quality by limiting CO_2 by 1.755% (0.159%) and ecological footprint by 1.469% (0.734%). Technological gradation in the industrial process has positive effects and supports achieving sustainability; technological innovation fosters environmental protection by lowering the degree of carbon emission in the ecosystem and protecting the ecological imbalance by controlling the waste emitted into the environment.

4.2 Asymmetric long-run and short-run coefficients: NARDL

The asymmetric coefficients of financial development (FD), foreign direct investment (FDI), good governance (GG), and technological innovation () on environmental degradation. The results in col [3] and [4] in Table 11 deal with the ED measures by carbon emission and ecological footprint. Referring to the symmetry rest see Panel –Cwith the standard Wald test, it is apparent that all the test statistics, i.e., $W_{FD}^{LR,SR}$; $W_{FDI}^{LR,SR}$; $W_{GG}^{LR,SR}$ & $W_{TI}^{LR,SR}$, ave exposed statistically significant at a 1% level, suggesting the rejection of the null hypothesis of symmetry. Alternatively, there is an asymmetric association between explained and explanatory variables in the long and short-run. The key outcome from the asymmetric assessment is stated below.

First, in terms of asymmetric coefficients of financial development (FD^{+}&FD^{-}) on ED disclosed a positive statistically significant connection in the long-run and short-run, which is valid for both model estimations. In the long run, a 1% positive (negative) change in financial development will result from the expedited (control) the environmental degradation $ED_{0.2583\%}^{CO2}$ ($ED_{0.2571\%}^{CO2}$) and $ED_{0.1811\%}^{EF}$ ($ED_{0.1562\%}^{EF}$). Moreover, in the short-run, the environmental degradation has amplified (lesser) by $ED_{0.0998\%}^{CO2}$ ($ED_{0.0928\%}^{CO2}$) and $ED_{0.1265\%}^{EF}$ ($ED_{0.1018\%}^{EF}$) due to a 1% increase (decrease) in FD. According to the asymmetric elasticities of FD on ED, the study postulated that controlled financial development has deterrent effects in managing the environmental depletion process. Effective environmental protection for project financing through credit extension has amplified green innovation and technological advancement, especially in operation. The credit facility with the environmental association eventually prompts environmental sustainability.

Second, the asymmetric coefficients of FDI (FDI^{+}&FDI^{-}) on ED disclosed negative and statistically significant at a 1% level in the long and short-run assessment. In the long run, the environmental degradation can be managed (increased) by lessening the degree of CO_2 emission by −0.1892 (−0.1769%) and ecological instability by −0.1964%(−0.2076%) through fostering (degrading) the inflows of FDI. Furthermore, the short-run exposed that positive (negative) innovation in FDI deals with improving environmental quality through condoling the CO_2 and improving the ecological ambiance.

Third, the asymmetric shocks of good governance on environmental degradation revealed negatively associated, suggesting the contributing role in improving the environmental quality through managing CO_2 emission and ecological footprint. In particular, a 10% improvement (decline) in good governance, in the long run, will result in the control of ED with the reduction (increment) of CO_2 by −1.622% (1.645%) and ecological footprint by 1.393% (1.653%). In the short-run, a positive (negative) innovation in GG improves (degrades) the environmental sustainability through the reduction (acceleration) of carbon emission and ecological instability, but the coefficients elasticity has been found less significant in comparison to long-run assessment. Referring to the magnitudes of asymmetric coefficients of GG, it is obvious that effective institutional quality is imperative in ensuring environmental security by contributing to efficient energy inclusion and operational development in light of lesser carbon concentration (Li u et al., 2022).

Fourth, the asymmetric nexus between technological innovation (TI^{+}&TI^{-}) and ED established a positive linkage between them, suggesting TI in the economy swift environmental excellence and ensure sustainability. More precisely, technological innovation in the industrial process manages the CO_2 and wastage emission in the ecosystem and energy efficiency, which eventually support environmental protection. In particular, a 1% positive (negative) variation in TI causes environmental development (further degradation) through the reduction (acceleration) of CO_2 by 0.2611% (0.1902%) and ecological footprint by 0.1715% (0.1588%). According to the elasticity of asymmetric shocks in IT, the study disclosed. Technological advancement significantly affects environmental adversity because energy efficiency and operational excellence ensure the reliance on clean energy, which leads to environmental development, especially in the long run (Li et al., 2019).

Next, the empirical Eqs 1, 2 has implemented following the framework proposed by Eberhardt (2012) commonly known as AMG and Correlated Effect Mean Group (CCEMG) by Pesaran (2006) methods for confirming the robustness in the long-run coefficient. The results of AMG and CCEMG estimation are displayed in Table 12. The coefficient sign of explanatory variables confirmed the empirical estimation robustness and efficiency in model construction. More precisely, the estimated results from AMG and CCEMG established a similar line of association between FD, FDI, GG, TI and ED.

4.3 Directional causality: Linear and Nonlinear effects of explanatory variables

The directional causality between FDI, FD, GG, CL and ED has been assessed through the causality framework familiarized by Dumitrescu and Hurlin (2012) and Table 13 reported the test statistics, i.e., W-stat. And Zbar-Stat, for casual assessment. In terms of casual linkage, the study established bidirectional causality between financial development and environmental degradation, i.e., FD←→CO_2; FD←→EF. The literature supports this by Shujah ur et al. (2019), Zhao and Qamruzzaman (2022), and Aluko and Obalade (2020), foreign direct investment and environmental degradation, i.e., FDI←→CO_2; FDI←→EF, which is in line with the literature. Furthermore, the unidirectional causality documented explains the causal association between good governance and environmental degradation [GG→CO_2; EF→GG] and clean energy and environmental degradation [CE→CO_2; CE→EF].

In the next, the causal association has extended with the asymmetric decomposition of explanatory variables and results of asymmetric D-H causality displayed in Table 14.

5 Discussion

The coefficient of financial development revealed positive statistically significant at a 1% level, suggesting that financial development contributes to adverse effects on environmental degradation, validated in CO_2 and EF as a proxy of ED. Our study findings align with existing literature (Adams and Klobodu, 2018; Shujah ur et al., 2019; Muneeb et al., 2022) but contrast with the study findings revealed in the study of Aluko and Obalade (2020). According to these findings, increasing the size of the financial system negatively affects the environment since it results in greater amounts of carbon emissions. It also demonstrates that the size of financial intermediation has a higher influence on carbon emissions than financial development indicators but a lower impact on efficiency. This is shown by the correlation between the two is positive. The findings indicate that the indicators of the stock market have a significant impact on carbon emissions; nevertheless, they are not adequate measurements of the expansion of the financial system. The results of the research indicate that foreign direct investment (FDI), in comparison to other indicators of economic development, seems to have a lesser influence on emissions of greenhouse gases (Li et al., 2022).

In terms of FDI elasticity's derived through the implementation of an empirical model with CSARDL and NARDL, it established an amplifying role towards environmental sustainability, suggesting the adverse association between FDI and environmental degradation measured by CO_2 and iconological footprint. The study findings align with the literature (Zhu et al., 2016) but disagree with the findings offered by Mia et al. (2014), Chenran et al. (2019), and Paramati et al. (2021). Referring to the FDI elasticities from the CSARDL investigation, the study advocated a 10% change in the FDI in the sample nations will augment the environmental sustainability through the contraction of CO_2 emission by 0.875% (0.221%) and ecological progress by 1.058%(0. 197%). Furthermore, asymmetric assessment suggested a 10% positive (negative) variation in FDI results in control (amplification) in environment sustainability (degradation) in terms of CO_2 injection by1.892% (1.769%) and ecological imbalance by 1.964% (2.076%). FDI may affect environmental sustainability regarding CO_2 reduction *via* size, method, and composition influences. According to the scale effect, greater degrees of economic liberalization may result in a rise in carbon dioxide emissions due to the influence of foreign direct investment on economic activity. This is due to the scale effect, which asserts that increasing degrees of economic liberalization may increase carbon dioxide emissions. The liberalization of the economy leads to an increase in total output, which in turn leads to an increase in total energy consumption, which has a negative impact on environmental quality as a result of an increase in carbon emissions (Pazienza, 2015; Andriamahery and Qamruzzaman, 2022; Qamruzzaman, 2022b; Hamid et al., 2022; Liu and Ma, 2022; Zhuo and Qamruzzaman, 2022). According to Shahbaz et al. (2020b), the relationship between foreign direct investment (FDI) and greenhouse gas emissions is contingent on the relationship between FDI and economic development.

Studies revealed that institutional quality has positive effects on environmental development. Alternatively, effective and efficient economic institutions foster environmental protection by reducing CO_2 emissions in the ecosystem and augmenting ecological stability. Our study findings are supported by the literature (Gani, 2012; Miao and Qamruzzaman, 2021). Expressly, a 1% change in GG results in improved environmental quality by lowering the carbon emission by −0.1031% and ecological footprint by −0.1593% in the long run. Furthermore, in the short-run, the ED has controlled through CO_2 emission contraction by −0.0268% and ecological footprint by −0.0550%. In terms of GG elasticity in the long-run and short-run assessment, it is apparent that the beneficial role of GG on environmental advancement is more obvious in the long run in comparison to the short-run. The possible reason is that good governance ensures socioeconomic stability by effectively enforcing overall social and economic protection, including environmental degradation, eventually inducing quality of the environment. Kirkpatrick and Parker (2004) advocated that good governance has a catalyst role in economic transition, indicating the promotion of industrialization with the inclusion of environmental protection through lowering the degree of carbon emission (CO_2). The effects of good governance in achieving environmental sustainability can be detected either through a director/indirect channel. In terms of direct influence of institutional quality on environmental degradation can be observed with the effective implementation of *rule of law*, postulating that society with direct guidance and strict instruction focusing on environmental rules and penalties in case of disobey injects pressure for the industry to consider any operational decision. Moreover, effective institutions protect investor interests and property rights, which offers firms for capitalizing the opportunity for earning maximization with the assurance of environmental protection(Li and Qamruzzaman, 2022; Xia et al., 2022; Zhuo and Qamruzzaman, 2022)

Fourth, Inferring to the coefficients of TI in the long-run (short-run), it is apparent that the present state of environmental status can be improved by lowering the CO_2 injection in the ecosystem and ecological footprint, indicating that technological innovation uplift environment degradation, implying the environmental degradation has a negative tie with technological innovation. In particular, a 1% change in IT will improve environmental quality by limiting CO_2 by 1.755% (0.159%) and ecological footprint by 1.469% (0.734%). Technological gradation in the industrial process has positive effects and supports achieving the environment sustainably. Technological innovation fosters environmental protection by lowering the degree of carbon emission in the ecosystem and protecting the ecological imbalance by controlling the waste emitted to the environment.

6 Conclusion and policy suggestions

The motivation of the study is to gauge the effects of financial development, FDI, governmental effectiveness and technological innovation on environmental degradation in Arab Nations for the period 1995-2018. For evaluating the empirical nexus and documenting the elasticity's of explanatory variables on environmental degradation, the study has implemented a slop of homogeneity test, cross-sectional dependency test, panel unit root test following CIPS and CADF and error correction based panel cointegration test. The long-run and short-run coefficients have been documented through CS-ARDL and Nonlin-ear ARDL. Finally, the directional association is exposed by executing the D-H causality test. The key findings are as follows.

First, referring to the SHT and CSD test results, the study revealed that research units had shared certain common dynamics with heterogeneity properties. Additionally, the results of CIPS and CADF established variables order integration after the first. The cointegration test following error correction residual based confirmed the long-run association between explained and explanatory variables.

Second, Referring to the long-run and short-run elasticity's extracted from CS-ARDL, it is apparent that financial development has a detrimental effect on environmental sustainability, suggesting the augmentation of CO_2 emission and ecological instability with the credit facilities for industrial progress. At the same time, the coefficients of FDI, GG, and TI have exposed beneficial effects in mitigating environmental adversity.

Third, the study implemented a nonlin-ear framework for documenting the asymmetric shocks of FD, FDI, GG and TI on ED. Inferring the test statistics derived from a Wald standard test, it is apparent that asymmetric effects run from explanatory variables to environmental degradation, which CO_2 and ecological footprint measure. Referring to revealed long-run and short-run asymmetric effects, the study unveiled positive and statistically significant association between FD and ED, while negative and statistically significant linkage exposed FDI, GG, and TI with ED. A study suggests that control of financial benefits for industrial development and environmental policies can boost environmental development. On the other hand, inflows of FDI, better institutional presence and technological innovation are revealed as a catalyst and beneficial for environmental improvement.

Fourth, the directional association, the test statistics exposed bidirectional causality between FDI, TI and ED [FDI←→ED; TI←→ED]. Furthermore, the asymmetric causality exposed feedback hypothesis holds in highlighting the causal association between ED←→ FDI^{-}; ED←→ FD^{+}; ED←→ FD^{-}.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: World Bank data bank, international financial statistics, Global network.

Author contributions

SJ: Conceptualization, Data curation and first draft. MQ: Literature survey, estimation, Discussion and final preparation. SK: Conceptualization; literature survey. AA: methodology; estimation and first draft preparation.

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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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Research on environmental regulation, environmental protection tax, and earnings management

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After the Chinese government put forward carbon peaking and carbon neutrality goals, the intensity of environmental regulation has reached an unprecedented height. Using a sample of heavily polluted A-share listed companies in Shanghai and Shenzhen from 2012 to 2018, we discuss the influence mechanism of environmental regulation and environmental tax on corporate earnings management in this study. We use multiple regression models to empirically verify the impact of environmental regulation, environmental tax, and their combined effect on corporate earnings management. We find that environmental regulations promote enterprises' upward real earnings management and inhibit enterprises' upward accrual earnings management. However, environmental taxes discourage firms from upward accrual earnings management. Moreover, environmental regulations and environmental tax jointly promote enterprises' upward accrual earnings management and real earnings management. And there is heterogeneity among different enterprise natures, different enterprise sizes, enterprises in regions with different degrees of marketization, different intensities of government investment in environmental protection, and whether enterprises disclose their environmental protection concepts. The contribution of this paper is to put environmental regulation, environmental protection tax, and earnings management in the same analytical framework. We aim to combine the government's macro policy with the enterprise's micro behavior and to deeply analyze the impact and mechanism of environmental regulation, environmental protection tax, and their combined effect on enterprise earnings management. By analyzing the heterogeneity of these impacts from multiple dimensions, this study tries to expand the research horizon, fill the research gap, and provide theoretical support for the government to formulate comprehensive environmental regulation policies.

KEYWORDS

environmental regulation, environmental protection tax, earnings management, accrual earnings management, real earnings management

1 Introduction

Currently, China's environmental protection still lags behind economic development, and high emissions, high pollution, and high energy consumption are still difficult problems hindering environmental protection. In 2020, the Chinese government made arrangements for peak carbon neutrality and formulated implementation plans for vital energy, industry, and transportation industries. It established a "1 + N″ policy framework for peak carbon neutrality. The 2022 National Conference on Ecological and Environmental Protection further proposed that pollution should be controlled precisely, scientifically, and law-based. The battle to protect blue skies, clear water, and pure land should be intensified. The meeting proposed to vigorously promote the comprehensive green transformation of economic and social development, to improve environmental governance capacity while stabilizing energy-intensive industries to meet pollution emission standards, and to further push environmental protection and governance to a new height (He and Walheer, 2020).

Enterprises are the main body of environmental governance, but enterprise environmental governance is often not voluntary but the result of environmental regulation. As a “rational” economic man, enterprises will make the corresponding reaction under the pressure of environmental regulation, and earnings management is one of them. The definition of earnings management refers to that under the premise of not violating accounting standards, enterprise managers adjust financial statements or change the short-term profitability of enterprises in other ways to maximize their interests.

Environmental regulation is an essential means of environmental protection and governance implemented by the government to overcome the market failure caused by improper use of the environment in economic activities. It is also a way for the government to intervene in economic activities. Environmental regulation is to effectively protect and improve the ecological environment and take sustainable economic development as the goal. Environmental protection tax is a tax levied by the state on the exploitation and utilization of resources, damage to the environment, and other behaviors, to regulate the behavior of enterprises, especially heavy polluters, to ensure the country’s green development. Environmental regulation mainly uses administrative control means to solve environmental problems. For example, the Chinese government continues to improve the assessment system linking environmental protection with political performance assessment. It constantly strengthens the punishment system of environmental protection and law enforcement of environmental protection. Environmental protection tax is an effective system arrangement of economic inducement. It makes more use of market incentive means to guide and adjust the micro behavior of enterprises. For example, it encourages enterprises to innovate or use more environmentally friendly new models, technologies, and processes to solve environmental problems. Therefore, the environmental protection tax has attracted more extensive and in-depth attention.

Will the increasingly stringent environmental regulation and the increasingly improved environmental protection tax system affect the earnings management behavior of enterprises? If so, what is the impact? This paper attempts to establish an analytical framework and conduct an empirical analysis to answer the above questions.

The contribution of this paper is to put environmental regulation, environmental protection tax, and earnings management in the same analytical framework. We aim to combine the government’s macro policy with the enterprise’s micro behavior and to deeply analyze the impact and mechanism of environmental regulation, environmental protection tax, and their combined effect on enterprise earnings management. We analyze the heterogeneity of these impacts from multiple dimensions, expand the research horizon, fill the research gap, and provide theoretical support for the government to formulate comprehensive environmental regulation policies.

Section 2 is the literature review for this study. In Section 3, we discuss the research mechanism and present our hypothesis. Sections 4, 5 present the research design, empirical findings, and analysis. In Section 6, we present concluding remarks and recommendations.

2 Literature review

As for environmental regulation, most scholars believe that environmental regulation has positive effects. Porter hypothesis holds that implementing appropriate and reasonable environmental regulation policies can help stimulate the technological innovation vitality of enterprises, make up for the cost increase caused by environmental regulation, and obtain the “innovation compensation effect.” Simpson and Bradford (1996) further explained the Porter hypothesis from the market failure perspective. They believe that when there is imperfect competition among enterprises, the implementation of strict environmental regulation can encourage enterprises to actively balance the goal of profit maximization and environmental protection, help domestic industries improve their competitiveness, gain strategic advantages, and achieve the “win-win” goal of profit and environmental protection. Based on the resource-based view of enterprises, Hart (1995) proposed the natural resource-based view of enterprises. The relationship between enterprises and the natural environment will be the basis of enterprises’ competitive advantage. It helps to enhance the competitive advantage of enterprises and improve their performance. Kang and Ru (2020) used the bilateral stochastic Frontier model to decompose the innovation compensation effect, compliance cost effect, and the net effect of environmental regulation on green innovation efficiency and analyzed their common characteristics. The results show that the compliance cost effect of environmental regulation on green innovation efficiency is smaller than the innovation compensation effect, making the comprehensive effect of environmental regulation positive, which verifies the Porter hypothesis.

On the contrary, Aupperle et al. (1985) believed that due to the influence of externalities of corporate social responsibility, enterprises undertake more social responsibilities, such as environmental protection, which can produce good social benefits. However, for enterprises, if limited resources are used to undertake more social responsibilities, compared with enterprises that do not undertake or undertake fewer social responsibilities, it will increase some additional costs and expenses and face higher opportunity costs, which may put the enterprise at a relative disadvantage, thus reducing its competitive advantage and ultimately harming corporate performance. Walley and Whitehead (1994) believed enterprises only passively improved their environmental governance under government regulation. Improving environmental performance under government coercion may force enterprises to increase costs. Enterprises will have to transfer limited funds from other projects with more potential to projects used to reduce environmental pollution. As a result, the improvement of enterprise productivity and competitiveness will be affected. Palmer et al. (1995) also believed that enterprises are bound to invest more human resources and capital in energy conservation and emission reduction, which will increase the operation management cost and sunk cost. The ultimate result is the loss of enterprise competitiveness and enterprise performance. Ambec and Barla (2002) further expanded Porter's hypothesis from the perspective of behavioral science. They pointed out that, due to the high uncertainty and long-term nature of R&D innovation activities, R&D innovation may help enterprises gain competitive advantages or long-term profits in the future, but it is challenging to bring profits to enterprises in the short term (Wang et al., 2021; Liu et al., 2022). Management's current preference may lead to delayed investment in research and development, which is not conducive to technological innovation. The pollution paradise hypothesis holds that the government's strengthening of environmental regulation will increase the private production cost of enterprises and reduce their competitiveness (Arouri et al., 2012).

As for environmental protection tax, most scholars believe that it also has positive effects. Environmental protection tax increases the pollutant discharge cost and tax burden of enterprises (Ye and Wang, 2017), resulting in the "crowding out effect" (Wang et al., 2019), affecting the regular operation of enterprises, inhibiting their development, and making enterprises face the risk of being eliminated (Aldy, 2016). When environmental protection tax is levied, enterprises will reduce the tax burden through technological innovation (Yu et al., 2019; Wang and Fan, 2021; Yang et al., 2022; Li et al., 2022a), optimizing resource allocation (Duan and Wang, 2017), and other ways to respond to achieve sustainable development of enterprises actively.

Earnings management is a strategic behavior of enterprises under the macro policy and business environment. From a professional perspective, earnings management can be divided into accrual earnings management and real earnings management. Accrual earnings management refers to the company's management adjusting the profit distribution of each accounting period through financial means within the scope of accounting standards. Real earnings management manages earnings distribution and cash flow in each period by manipulating earnings through real economic transactions such as asset sales and discount sales. The existing research on earnings management mainly starts from the traction of earnings management and studies the motivation of enterprise earnings management, which can be summarized into five aspects. The first is the motivation of management compensation. That is, facing the temptation of generous compensation, and the management will strengthen the control of the company's earnings behavior and change the company's financial statements by various means to meet the expectations of shareholders and investors to obtain more material benefits. There are two hypotheses on the motivation of managerial compensation: the interest convergence effect (Yuan et al., 2014) and the opportunistic behavior effect (He, 2016). The second is the motivation for debt contracts. Watts and Zimmerman (1986) proposed the debt contract hypothesis that enterprises will conduct earnings management to reduce the default cost of the company. The third is the motivation of capital market, including the motivation of stock issuance (Song et al., 2017; Li et al., 2022), the motivation of avoiding losses and delisting (Zhang and Wang, 2021), the motivation of achieving the target of earnings forecast (Kallunki and Martikainen, 1999) and the motivation of corporate M&A (Liu et al., 2021). The fourth motivation is regulatory motivation. With the growing strength of the capital market, relevant systems and regulations are also constantly improving, and the crackdown on corporate violations by market regulators is also increasing (Zhu and Li, 2021). Fifth, cost motivation, including political cost (Huang and Zhou, 2021) and tax cost (Wang et al., 2009).

To sum up, many scholars have conducted a lot of research on the motivation, preference, and implementation methods of earnings management. Some scholars have also studied the impact of environmental regulation on earnings management or the impact of environmental taxes on earnings management. However, no literature currently integrates environmental regulation, environmental tax, corporate accrual earnings management, and real earnings management into the same framework for systematic research. This paper theoretically studies the impact of environmental regulation and environmental tax on corporate earnings management and its internal mechanism. We selected the data of heavily polluted enterprises from Shanghai and Shenzhen A-share listed companies from 2012 to 2018 as samples for empirical analysis and verification. The empirical results of this paper provide a specific theoretical basis and empirical support for the formulation of composite environmental protection policies. Our paper makes the following contributions to the literature. First, we establish an analysis framework of environmental regulation, environmental tax, and earnings management. Second, we deeply analyze the impact of environmental regulation, environmental tax, and their combined effects on corporate earnings management and their mechanism. Finally, we further analyze the heterogeneity and causes of the impact of environmental regulation, environmental tax, and their combined effects on corporate earnings management to fill in the gaps in existing research.

3 Mechanism analysis and assumptions

3.1 Environmental regulation and earnings management

According to Pigou, when the producer's private marginal cost is inconsistent with the social marginal cost, that is, when a producer causes losses to other producers or the whole society without paying the price or the price paid is less than the loss caused by the producer, external diseconomy will occur, leading to the failure of market resource allocation. External diseconomy is often the reason for government intervention, and environmental regulation is typical. To achieve certain goals, enterprises often take certain measures to cope with government environmental regulations, such as earnings management.

In this study, environmental regulation refers to the government's mandatory supervision of enterprises' environmental behavior. Environmental regulation may prompt firms to engage in upward earnings management. Environmental pollution is a negative externality activity of enterprises. Higher company costs make them less attractive to investors and raise financing costs. Therefore, enterprises may conduct upward earnings management based on capital market motivation or management compensation motivation.

Environmental regulation may also encourage enterprises to conduct downward earnings management. Under environmental regulation, enterprises with negative environmental effects are bound to face stricter control and supervision from the government. Severe penalties can be imposed on these companies, such as fines, warnings, or suspension of production for rectification. Based on regulatory motivation, enterprises "crying poor" and conduct downward earnings management to reduce such risks.

Hence, we have the following hypotheses.

Hypothesis 1a: Environmental regulation can promote enterprises to conduct upward earnings management.

Hypothesis 1b: Environmental regulation can promote enterprises to conduct downward earnings management.

3.2 Environmental tax and earnings management

Unlike the compulsion of environmental regulation, environmental tax emphasizes the incentive adjustment of tax on enterprise behavior. Environmental protection tax encourages enterprises to save energy and reduce emissions, increase investment in research and development, play the role of "innovation compensation," and improve the efficiency of enterprise innovation. According to the Porter Hypothesis, appropriate environmental protection tax stimulates the innovation compensation effect of enterprises and makes up for their compliance costs. Environmental protection tax makes enterprises pay the social cost corresponding to their pollution, internalizes the cost of environmental pollution of enterprises, and strengthens the investment in environmental protection facilities and equipment. The legislative purpose and practical orientation of environmental protection tax differ from other taxes. Its starting point and foothold are to protect and improve the environment and promote ecological civilization construction. The introduction of environmental protection tax is to strengthen the regulatory role of tax, form an effective restraint and incentive mechanism, and fulfill the responsibility of polluters. According to the "Pigouvian tax" principle, collecting environmental protection will increase enterprises' costs, increase the marginal revenue of tax planning through earnings management, and encourage enterprises to conduct earnings management. Environmental protection tax is based on the number of pollutants discharged. The innovation of production mode and production technology further increases the cost of enterprises, thus promoting enterprises to carry out earnings management. Of course, environmental taxes reduce corporate profits for managers, so they also have the incentive to conduct earnings management to maximize private profits.

Hence, we have the following hypotheses:

Hypothesis 2a: Environmental tax will promote the upward earnings management of enterprises.

Hypothesis 2b: Environmental tax will promote the downward earnings management of enterprises.

3.3 Environmental regulation, environmental tax, and earnings management

Environmental regulation and environmental protection tax promote the internalization of enterprises' external costs. Environmental regulations deprive polluters of choice, and firms must comply with environmental regulations or face penalties. Although environmental regulation can restrain enterprises' environmental pollution behaviors, it also has problems such as high enforcement costs and damage to enterprise efficiency. Based on the market, environmental protection tax guides the behavior of enterprises through market signals. It encourages polluters to reduce the level of pollution discharge or stop polluting so that the overall pollution situation of society tends to be controlled and improved. Therefore, environmental protection tax is an incentive for environmental regulation based on the market. It gives enterprises a degree of choice and encourages them to adopt cheap and better pollution control technology. Secondly, there is a time-lag effect in the response of enterprises to the environmental protection tax, and it takes some time to reveal its effect. Environmental regulation is mandatory, while environmental protection tax is an incentive tool—combining the above two influences enterprise behavior from different angles. For example, it stimulates enterprises to innovate environmental protection technology and production model. Enterprise innovation activities increase short-term costs but also increase long-term benefits. Therefore, enterprises may conduct different types and degrees of earnings management based on long-term and short-term strategies.

Hence, we have the following hypotheses:

Hypothesis 3a: Environmental regulation and environmental tax work together to promote the upward earnings management of enterprises.

Hypothesis 3b: Environmental regulation and environmental tax work together to promote the downward earnings management of enterprises.

4 Research design

4.1 Data and samples

Our sample covers A-share heavily polluted listed companies in Shanghai and Shenzhen stock exchanges between 2012 and 2018.[1] We select the samples as follows: 1) Select the listed companies in the 2008 classified management list of listed companies' environmental verification industry of the Ministry

1 In February 2012, China promulgated ambient air quality standards. Considering the policy impact, the data before 2012 are not selected. After 2018, some data have changed in statistical caliber. Due to the impact of COVID-19, the production and operation of Chinese enterprises from 2020 to 2022 are not normal, so the relevant data are not consistent and comparable. Combined with the availability of data and the consistency of statistical caliber, this paper selects data from 2012 to 2018 as research samples.

TABLE 1 Environmental regulation evaluation system.

Content	Definition of indicators	Computing formula
Wastewater	Industrial wastewater discharge per unit of GDP	Wastewater discharge/GDP
Waste gas	Industrial SO2 emissions per unit of GDP	SO2 emissions/GDP
	Industrial dust emissions per unit of GDP	Industrial smoke and dust emissions/GDP

Second, we use the extreme value method to standardize each dimension index.

of Environmental Protection; 2) Eliminate ST and ST* enterprises, enterprises with missing data and financial enterprises; 3) Eliminate enterprises with abnormal data. At the same time, to avoid the influence of extreme values, the main continuous variables are winsorized at the level of 1% and 99%. The data of this paper comes from the CSMAR (China Stock Market Accounting Research) database.

4.2 Index construction

4.2.1 Explained variables

Accrual earnings management: We use the manipulated accruals calculated by the modified Jones model considering the impact of performance as the proxy variable of earnings management to analyze the impact of environmental regulations on corporate accruals, as defined in Table 2 and denoted as DA.

Real earnings management: According to Roychowdhury (2006), we calculate abnormal operating cash flow, abnormal expenses, and abnormal product costs to finally obtain the real earnings management index, which is recorded as REM and defined in Table 2.

4.2.2 Explanatory variables

4.2.2.1 Environmental regulation

Following Dong and Wang (2019) and Zhao et al. (2020), we use the environmental regulation index as the comprehensive evaluation index of environmental regulation. And we take this environmental regulation index as an explanatory variable. The calculation process is as follows:

First, we use the unit GDP emission as the dimension index, which is recorded as X_{ij}, as shown in Table 1.

$$Q_{ij} = \frac{X_{ij\_}min\,X_j}{max\,X_j - min\,X_j}, \left(i = 1, 2, \ldots\ldots 180;\, j = 1, 2, 3\right) \quad (1)$$

Among them, X_{ij} is the initial value of the jth index of the ith city (union, state), $max\,X_{ij}$; $min\,X_{ij}$ are the maximum and minimum values of the jth index; Q_{ij} is the jth index value of the ith city (union, state) after standardization.

Third, we calculate the adjustment coefficient of each dimension index. Different cities have different populations and economic development scales, and their pollutant emissions are also different. In order to strengthen the comparability of pollution emission levels in different cities, we introduce an adjustment parameter that reflects the intensity of *per capita* GDP pollution emission of each city. The adjustment factors are as follows:

$$W_{ij} = \frac{P_{ij}}{\overline{P_{ij}}} \Big/ PGDP_{it} \quad (2)$$

Among them, W_{ij} is the adjusted coefficient of each index of each city (union, state), P_{ij} is the type j pollutant discharge of city i (union, state), $\overline{P_{ij}}$ is the average amount of type j pollutants emitted by city i (union, state), $PGDP_{it}$ is the *per capita* GDP of the city i in phase t.

Finally, we calculate the city (union, state) environmental regulation index:

$$ER_i = \sum\nolimits_{j=1}^{3} Q_{ij} {*} W_{ij} \quad (3)$$

ER_i is the environmental regulation index of city i (union, state). It reflects the intensity of urban environmental regulation. The greater the value of ER_i, the greater the intensity of environmental regulation.

4.2.2.2 Environmental tax

Environmental protection tax emphasizes the incentive adjustment of tax on corporate behavior. The environmental protection tax is characterized by fees and taxes directly related to environmental protection. From 2012 to 2017, the environmental protection tax is replaced by sewage charges, plus resource tax, farmland occupation tax, urban maintenance and construction tax, travel tax, vehicle purchase tax, and urban land use tax, and 2018 is, the environmental protection tax.

4.2.3 Control variables

According to the research of Du et al. (2021), we select the following indicators as the control variables: corporate profitability (ROA), corporate Size (SIZE), corporate debt level (Leverage), Tobin Q (tobinq), board independence (independence), gross domestic product *per capita* (GDP), CEO and the chairman of the board is the same person (dual), whether or not it is audited by the four largest international firms (big). At the same time, considering the government's attention to environmental protection and whether the disclosure of environmental objectives by enterprises will affect the earnings of enterprises, we add the government's environmental concern (percentage) as the control variable. According to the research of Li et al. (2020); Li et al. (2021), considering the impact of corporate environmental responsibility on corporate behavior, the disclosure of environmental objectives (EPGoal) is added as the control variable.

Table 2 shows the definition of variables.

4.3 Model construction

Multiple regression analysis is an effective method to study the relationship between multiple variables. It can not only determine

TABLE 2 Definition of variables.

Type	Variable name	Variable definition	Variable description
Explained Variables	DA	accrual earnings management	Discretionary total accruals calculated by the modified Jones model allow for performance effects
	REM	Real earnings management	Real Earnings Management Level Measured by Roychowdhury's (2006) Model
Explanatory Variables	ER	Environmental regulation intensity	Based on the practices of Dong and Wang (2019) and Zhao et al. (2020), a comprehensive evaluation index of environmental regulations should be established
	fee	Environmental protection tax	Depict environmental tax with taxes directly related to environmental protection
Control variable	ROA	Profitability	Current net profit divided by total assets at the end of a period
	Size	Scale	Total assets at the end of the year take a natural logarithm
	Leverage	Debt level	Total liabilities at the end of the period divided by total assets at the end of a period
	tobinq	Tobin q	Market value at the end of the period divided by the book value of total assets
	independence	Independence of Board of Directors	The proportion of independent directors on the board of directors
	lnpgdp	Per capita GDP	The ratio of regional GDP to population is taken as the natural logarithm
	percentage	Government's environmental concern	Frequency of environmental protection words in government work reports
	dual	duality	If the chairman and general manager are the same people, take 1; otherwise, take 0
	soe	Enterprise nature	If the actual controller is state-owned, take 1; otherwise, take 0
	big	Whether the Big Four accounting firm	The value is 1 if a Big Four international firm audits it and 0 otherwise
	EPGoal	Whether to disclose the environmental protection concept?	Disclosure of the environmental protection concept is 1; otherwise, it is 0
	Industry	Industry dummy variable	The manufacturing industry is classified according to the secondary classification; others are classified according to the primary classification
	Year	Annual dummy variable	Take 2012 as the benchmark

whether there is a correlation between several specific variables but also predict or control the value of another variable according to the value of one or several variables and the accuracy it can achieve. It can also carry out factor analysis. For example, among many variables (factors) that jointly affect a variable, it could find out which are essential and which are secondary factors. This paper selects a multiple regression model to analyze better the impact of environmental regulation and environmental protection tax on earnings management and exclude the interference of other factors.

Firstly, we construct model one to verify the influence of environmental tax and environmental regulation on enterprises' accrual earnings management:

$$\mathrm{DA}_{i,t} = \beta_0 + \beta_1 fee_{i,t} + \beta_2 ER_{i,t} + \beta_3 \sum Control_{i,t} + \varepsilon_{i,t} \tag{4}$$

Secondly, based on model 1, we add the interaction term of environmental tax and environmental regulation. We construct model two to verify the joint effect of environmental tax and environmental regulation on enterprise accrual earnings management:

$$\mathrm{DA}_{i,t} = \beta_0 + \beta_1 fee_{i,t} + \beta_2 ER_{i,t} + \beta_3 fee_{i,t} \times ER_{i,t} + \beta_4 \sum Control_{i,t} + \varepsilon_{i,t} \tag{5}$$

Among Model 1 and Model 2, $\mathrm{DA}_{i,t}$ is accrual earnings management; $fee_{i,t}$ is environmental protection tax; $ER_{i,t}$ is environmental regulation intensity; $Control_{i,t}$ is control variables.

Thirdly, we construct model three to verify the influence of environmental tax and environmental regulation on the real earnings management of enterprises:

$$\mathrm{REM}_{i,t} = \beta_0 + \beta_1 fee_{i,t} + \beta_2 ER_{i,t} + \beta_3 \sum Control_{i,t} + \varepsilon_{i,t} \tag{6}$$

Fourthly, based on Model 3, we add the interaction term of environmental tax and environmental regulation. We construct Model four to verify the joint effect of environmental tax and environmental regulation on the real earnings management of enterprises:

$$\mathrm{REM}_{i,t} = \beta_0 + \beta_1 fee_{i,t} + \beta_2 ER_{i,t} + \beta_3 fee_{i,t} \times ER_{i,t} + \beta_4 \sum Control_{i,t} + \varepsilon_{i,t} \tag{7}$$

Among Model 3 and Model 4, $\mathrm{REM}_{i,t}$ is real earnings management; $fee_{i,t}$ is environmental protection tax; $ER_{i,t}$ is environmental regulation intensity; $Control_{i,t}$ is control variables.

TABLE 3 Descriptive statistics.

		Variable names	N	Mean	SD	Minimum	Median	Maximum
Interpreted Variable		DA	2,100	−0.005	0.056	−0.300	−0.006	0.306
		REM	2,100	−0.005	0.184	−1.243	0.006	0.684
Explanatory Variable		ER	2,100	4.636	3.533	0.109	3.750	29.226
		fee	2,100	8.059	5.593	0.310	6.518	25.411
Control Variable	Corporate Governance Structure	independence	2,100	0.369	0.052	0.300	0.333	0.571
		dual	2,100	0.174	0.379	0.000	0.000	1.000
		soe	2,100	0.652	0.476	0.000	1.000	1.000
		big	2,100	0.086	0.280	0.000	0.000	1.000
		EPGoal	2,100	0.261	0.440	0.000	0.000	1.000
	Enterprise Competitiveness	tobinq	2,100	1.886	1.106	0.872	1.531	7.138
		ROA	2,100	0.043	0.057	−0.100	0.030	0.241
		Size	2,100	22.769	1.262	20.285	22.595	26.458
		Leverage	2,100	0.466	0.182	0.072	0.470	0.861
	Macroenvironment	lnpgdp	2,100	11.276	0.801	9.177	11.288	13.135
		percentage	2,100	0.007	0.002	0.003	0.007	0.011

4.4 Descriptive statistical analysis of data

Table 3 presents the descriptive statistics for the main variables used in the analysis. The samples of this paper are 300 heavy pollution A-share listed companies in the Shanghai and Shenzhen Stock markets, with a total of 2,100 firm-year observations from 2012 to 2018.

The average value of accrual earnings management and real earnings management in the table is less than 0, indicating that enterprises are more inclined to conduct downward earnings management. The average value of environmental protection tax is 8.059, which is greater than the median, indicating that the intensity of environmental protection tax collection in most regions is lower than the average level. The average value of environmental regulation is 4.636, which is greater than the median, indicating that the intensity of environmental regulation in most regions is lower than the average level.

5 Analysis of empirical results

5.1 Analysis of basic results

According to the research hypothesis, we empirically analyze the influence of environmental regulation, environmental tax, and the joint effect of environmental regulation and environmental tax on enterprise earnings management. Table 4 shows the results of the full sample moderating effect analysis.

Model one shows that the coefficient between environmental regulation and enterprise accrual earnings management is negative but not significant, indicating that environmental regulation has no significant impact on enterprise accrual earnings management. With the strengthening of environmental regulations, enterprises face more substantial supervision. As a result, it is more difficult for enterprises to manage their accrued earnings. As we can see from Table 4, environmental regulations have no significant impact on their accrual earnings management. The environmental tax has a significant negative effect on the enterprise accrual earnings management, which indicates that the environmental tax will promote the enterprise to conduct downward accrual earnings management. We can see from Table 4 that 100 units increase in environmental tax will increase enterprises' downward earnings management level by 0.6 units. To conduct tax planning, enterprises will conduct downward accrual earnings management.

Model two shows that the interaction term of environmental regulation and environmental tax has a positive but not significant coefficient on enterprise accrual earnings management, indicating that the interaction term of environmental regulation and environmental tax has no significant impact on enterprise accrual earnings management. Intense supervision of environmental regulations makes it more difficult for enterprises to conduct accrual earnings management, and it is easy to be caught as "typical."Even if enterprises have the motivation to conduct accrual earnings management under the combined effect of environmental regulation and environmental protection tax, they will avoid implementing it or seek other methods.

In Model 3, the estimated coefficient on environmental regulation is significantly positive, indicating that environmental regulation will promote upward real earnings management. When the intensity of environmental regulation increases by 100 units, the enterprise's upward real earnings management level increases by 0.4 units. Environmental regulation increases the cost of enterprises and encourages enterprises to carry out upward real earnings management to obtain more investment, financing, or other benefits.

Moreover, real earnings management is more hidden. Environmental taxes have no significant effect on real earnings

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TABLE 4 Results of full sample analysis.

	Model 1	Model 2	Model 3	Model 4
	DA	DA	REM	REM
ER	−0.0002	−0.0009*	0.0040***	0.0006
	(-0.61)	(-1.69)	(3.99)	(0.37)
fee	−0.0006**	−0.0012**	−0.0010	−0.0040**
	(-2.39)	(-2.33)	(-1.25)	(-2.54)
ER×fee		0.0001		0.0007**
		(1.56)		(2.55)
ROA	−0.0124	−0.0090	−1.2490***	−1.2330***
	(-0.35)	(-0.25)	(-11.60)	(-11.40)
Size	0.0051***	0.0048***	−0.0015	−0.0026
	(3.55)	(3.35)	(-0.33)	(-0.58)
Leverage	−0.0171*	−0.0164	0.0522*	0.0554*
	(-1.67)	(-1.60)	(1.80)	(1.90)
tobinq	−0.0028*	−0.0028*	−0.0137**	−0.0137**
	(-1.68)	(-1.69)	(-2.11)	(-2.13)
Independence	0.0019	0.0002	0.0507	0.0428
	(0.07)	(0.01)	(0.79)	(0.66)
lnpgdp	−0.0006	−0.00004	0.0066	0.0091
	(-0.32)	(-0.02)	(1.22)	(1.63)
percentage	−0.8830	−0.9120	1.5840	1.4480
	(-1.24)	(-1.28)	(0.84)	(0.76)
dual	0.0009	0.0008	0.0029	0.0025
	(0.25)	(0.22)	(0.26)	(0.22)
soe	0.0112***	0.0111***	0.0495***	0.0490***
	(4.07)	(4.04)	(6.02)	(5.98)
big	−0.0164***	−0.0164***	−0.0747***	−0.0744***
	(-3.88)	(-3.86)	(-4.68)	(-4.67)
EPGoal	−0.0041	−0.0042	0.0116	0.0109
	(-1.41)	(-1.45)	(1.49)	(1.41)
industry	control	control	control	control
year	control	control	control	control
N	2,100	2,100	2,100	2,100
R^2	0.031	0.032	0.266	0.268

NOTE: t statistics in parentheses.
$^{*}p < 0.1$.
$^{**}p < 0.05$.
$^{***}p < 0.01$.

management, and the real earnings management of enterprises will distort the normal business activities of enterprises. The environmental tax encourages enterprises to innovate and gives play to the "innovation compensation" effect to make up for the cost brought by the environmental tax. At this point, the environmental tax has an insufficient driving force on the real earnings management of enterprises.

Model four shows that the interaction term of environmental regulation and environmental tax has a significant positive coefficient on corporate real earnings management, which indicates that the joint effect of environmental regulation and environmental tax will promote corporate real earnings management. Both environmental regulation and environmental tax will increase the cost of enterprises and bring financial pressure to enterprises. To relieve this pressure, enterprises carry out upward real earnings management.

To sum up, the results verify Hypothesis H1a: environmental regulation promotes enterprises to conduct upward real earnings management. The results verify H2b: environmental protection tax will promote enterprises to conduct downward accrual earnings management. The results also verify H3a: the joint effect of environmental regulation and environmental protection tax promotes upward real earnings management of enterprises.

In terms of the influence of control variables on accrual earnings management, the coefficients on enterprise size and enterprise nature are significantly positive, indicating that state-owned enterprises and large enterprises tend to conduct upward accrual earnings management. State-owned and large-scale enterprises have non-market motives such as political seeking and job promotion in earnings management. There is a channel for managers of state-owned and large-scale enterprises to choose positions between enterprises and the government. For example, many executives of state-owned enterprises are promoted to government positions and even local party committees. Some prominent enterprise executives can also hold positions in the National People's Congress, the Chinese People's Political Consultative Conference, and other institutions. Therefore, managers seeking political interests or promotion opportunities may promote enterprises to conduct upward accrual earnings management.

The coefficients on corporate debt level, Tobin's Q, and whether audited by the Big Four auditing firms are significantly negative, indicating that companies with high debt levels, high Tobin's Q value, and audited by the Big Four firms tend to conduct downward accrual earnings management. One of the reasons is to "cry poor" to seek favors or a more favorable external environment, such as tax breaks, government subsidies, or less stringent environmental regulations.

The coefficients on corporate profitability, board independence, *per capita* GDP, government's attention to environmental protection, duality (CEO and the chairman of the board are the same people), and whether to disclose corporate environmental protection goals are not significant, indicating that these factors have no significant impact on corporate accrual earnings management. The above results are consistent with the conclusion of corporate earnings management motivation analysis. The main factors affecting corporate earnings management are not strongly related to the corporate governance structure and regional economic development level.

From the perspective of the influence of control variables on real earnings management, the coefficients on corporate debt level and corporate nature are significantly positive, indicating that state-owned enterprises and enterprises with high debt levels tend to conduct upward real earnings management. The desire of highly indebted enterprises and state-owned enterprises to hide their operating conditions through real earnings management is more apparent, and the concealment of real earnings management is relatively good. The phenomenon is that enterprises with high debt levels and state-owned holding enterprises are more likely to conduct upward real earnings management, which may be related to enterprise performance, executive compensation, and employee welfare. Those are also the common motivation of enterprise earnings management. The coefficients on corporate profitability, Tobin's Q, and whether audited by the Big Four auditing firms are significantly negative, indicating that companies with high profitability, high Tobin's Q value, and audited by the Big Four firms are unwilling to conduct upward real earnings management. Consistent with the motivation hypothesis of corporate earnings management, firms with high profitability, large Tobin's Q value, and firms audited by the Big Four firms do not have the inherent demand for upward earnings management. Some enterprises may also conduct downward earnings management to "leave the room" for the future and "wiggle room" in operation.

The coefficients on enterprise size, board independence, *per capita* GDP, government attention to environmental protection, duality (CEO and the chairman of the board are the same people), and disclosure of corporate environmental objectives are not significant, indicating that these factors have no significant impact on real earnings management of enterprises. As mentioned above, the results are consistent with the conclusions of corporate earnings management motivation analysis. The main factors affecting corporate earnings management are not strongly correlated with a corporate governance structure and regional economic development level.

5.2 The robustness test

Different measurement criteria may have different effects on the results. For Model one and Model two in Table 5, we use the modified Jones model to estimate the expected discretionary accruals each year using all the firm-year observations. We denote the final calculated result as DA2. For Model three and Model four in Table 5, we follow Li (2009) in measuring the enterprise real earnings management level (REM2). Then we use the above two calculated results (DA2 and REM2) to analyze the reliability of the test results. Table 5 presents the robustness test results.

In Model one and Model 2, the explained variable is accrual earnings management (DA2), which the modified Jones model measures. The results of Model one and Model two show that the coefficients on environmental regulation and environmental tax are negative but not significant. Model two shows that the interaction term of environmental regulation and environmental tax is positive but insignificant. This result is consistent with the previous results when the modified Jones model calculates the accrual earnings management (DA) with a performance impact. Consequently, the robustness test further verifies the validity of the previous analysis.

In Model three and Model 4, we follow Li et al. (2009) to measure the real earnings management level (REM2). Model three shows that the coefficient on environmental regulation is significantly positive. Model four shows that the interaction term of environmental regulation and environmental protection tax is significantly positive. It is consistent with the analysis results when the real earnings management level (REM) of enterprises is measured by Roychowdhury's (2006) model. To sum up, the results obtained from the models we constructed in this study are robust.

TABLE 5 Robustness test.

	Model 1	Model 2	Model 3	Model 4
	DA2	DA2	REM2	REM2
ER	−0.0003	−0.0010	0.0035***	−0.0003
	(-0.80)	(-1.57)	(3.16)	(-0.16)
fee	−0.0005**	−0.0011**	−0.0008	−0.0042***
	(-2.11)	(-2.02)	(-1.15)	(-2.83)
ER×fee		0.0001		0.0007***
		(1.33)		(2.94)
control variable	Yes	Yes	Yes	Yes
industry	control	control	control	Control
year	control	control	control	Control
N	2,100	2,100	2,100	2,100
R^2	0.133	0.134	0.172	0.175

NOTE: t statistics in parentheses.
*$p < 0.1$.
**$p < 0.05$.
***$p < 0.01$.

5.3 Further analysis

5.3.1 Heterogeneity analysis of accrual earnings management based on profit adjustment

To further discuss the impact of environmental regulation and environmental protection tax on the enterprise's accrual earnings management, we divide enterprises' accrual earnings management into the accrual earnings management of increasing profits and the accrual earnings management of reducing profits. Table 6 shows the results of the heterogeneity analysis.

The results of Model 1A show that the coefficient on environmental regulation and environmental tax is significantly negative, indicating that environmental regulation and environmental tax will inhibit enterprises from increasing profit accrual earnings management. For every 100 units increase in the intensity of environmental regulation, the enterprises' profit-increasing accrual earnings management will decrease by 0.15 units. For every 100 units of environmental protection tax increase, the enterprises' profit-increasing accrual earnings management will decrease by 0.04 units. Based on the regulation motivation, enterprises are unwilling to carry out upward accrual earnings management to avoid higher supervision intensity.

TABLE 6 Calculation results of accrual earnings management based on profit adjustment.

	Model 1A	Model 2A	Model 1B	Model 2B
	DA ≥ 0	DA ≥ 0	DA<0	DA<0
ER	−0.0015***	−0.0024***	0.0012***	0.0007
	(-4.18)	(-4.36)	(3.69)	(1.34)
fee	−0.0004*	−0.0013**	−0.0003*	−0.0007
	(-1.74)	(-2.46)	(-1.65)	(-1.45)
ER×fee		0.0001**		0.0001
		(1.98)		(1.02)
control variable	Yes	Yes	Yes	Yes
industry	control	control	control	control
year	control	control	control	control
N	939	939	1,161	1,161
R2	0.058	0.061	0.079	0.080

NOTE: t statistics in parentheses.
*$p < 0.1$.
**$p < 0.05$.
***$p < 0.01$; Model 1A and Model 1B are the derived models of Model one when accrual earnings management is greater than or equal to 0 and less than 0, respectively. Model 2A and Model 2B are the derived models of Model two when accrual earnings management is greater than or equal to 0 and less than 0, respectively.

Model 2A shows that the interaction term of environmental regulation and environmental tax is significantly positive, indicating that the combined effect of environmental regulation and environmental tax will promote the enterprise to conduct profit-increasing accrual earnings management. Under the joint action of environmental regulation and environmental tax, enterprises are under more significant financial pressure due to rising costs. Based on the motivation of the capital market, enterprises will carry out upward accrual earnings management in this situation.

Model 1B shows that environmental regulation has a significant positive effect on accrual earnings management, which indicates that environmental regulation can promote enterprises to carry out profit-decreasing accrual earnings management. For every 100 units increase in the intensity of environmental regulation, the enterprises' profit-decreasing accrual earnings management will increase by 0.12 units. For these enterprises, environmental regulations lead to rising costs. Then the downward accrual earnings management will bring financing pressure. Therefore, enterprises are reluctant to carry out downward accrual earnings management based on the motivation of the capital market.

Model 2B shows that the interaction coefficient of environmental regulation and environmental tax is positive but insignificant, indicating that the joint effect of environmental regulation and environmental protection tax has no significant impact on enterprises' profit-reducing accrual earnings management.

5.3.2 Heterogeneity analysis based on internal and external factors

We grouped and analyzed the nature of enterprise ownership, the scale of production, the degree of marketization, the scale of environmental protection investment by the local government, whether the enterprise disclosed environmental protection targets, and different environmental protection actions taken by the enterprise. Table 7 presents the results.

5.3.2.1 Group analysis according to the nature of enterprise ownership

Environmental regulations inhibit the upward accrual earnings management in state-owned and non-state-owned enterprises, promote the upward real earnings management in state-owned enterprises, and inhibit the upward real earnings management in non-state-owned enterprises. After the state-owned enterprises bear the social responsibility, the cost pressure brought by the environmental regulation encourages the state-owned enterprises to carry out upward earnings management because of the financing motivation or management political motivation. Non-state-owned enterprises face more substantial supervision and are more inclined to carry out upward real earnings management because real earnings management is more hidden.

Environmental tax inhibits non-state-owned enterprises from upward accrual earnings management and real earnings management. Generally, non-state-owned enterprises have more substantial incentives to conduct tax planning or tax avoidance and are more motivated to conduct earnings management.

The joint effect of environmental regulation and environmental protection tax promotes the upward accrual earnings management in state-owned enterprises and the upward real earnings management in non-state-owned enterprises. Under the joint action of environmental regulation and environmental tax, the cost of enterprises rises, so enterprises tend to carry out upward earnings management to a certain extent. State-owned enterprises undertake more social responsibilities, so they choose accrual earnings management that is harmless for their operating

TABLE 7 Results of group analysis.

Grouping basis	Variable name	DA (DA≥0)		REM	
		0	1	0	1
Soe	ER	−0.0033***	−0.0010***	−0.0041**	0.0069***
	fee	−0.0009*	0.0001	−0.0043***	0.0009
	ER×fee	0.0002	0.0002*	0.0010**	0.0005
Size	ER	−0.0014**	−0.0016***	0.0051***	0.0026**
	fee	−0.0005	−0.0002	0.0003	−0.0025**
	ER×fee	0.0002	0.0001	0.0002	0.0014***
Market	ER	−0.0012	−0.0016***	0.0058***	0.0028**
	fee	0.0001	−0.0004	0.0012	−0.0015*
	ER×fee	0.0001	0.0001	0.0009**	0.0005
Envir	ER	−0.0018***	0.0013	0.0043***	0.0084
	fee	−0.0008**	−0.0005	0.0010	−0.0049**
	ER×fee	0.0002	0.0002	0.00004	0.0015***
EPt	ER	−0.0012**	−0.0019***	0.0061***	0.0021
	fee	−0.0007**	−0.0000005	−0.00003	−0.0019*
	ER×fee	0.0002*	−0.0000002	0.0006*	0.0007*

NOTE: Denote significance at.
*$p < 0.1$.
**$p < 0.05$.
***$p < 0.01$.

income. Non-state-owned enterprises may choose more hidden real earnings management to avoid supervision.

5.3.2.2 Group analysis according to the size of the enterprise

Regardless of the size of enterprises, environmental regulation inhibits upward accrual earnings management and promotes upward real earnings management, and there is no significant difference between groups.

Environmental protection tax inhibits the upward real earnings management of large-scale enterprises. Large-scale firms face a more extensive tax base, and the gains from tax planning are more significant, so they choose to engage in downward real earnings management.

The joint effect of environmental regulation and environmental protection tax promotes large-scale enterprises' upward real earnings management. Under the joint action of environmental regulation and environmental protection tax, enterprises' cost increases. Large-scale enterprises have a great demand for capital and face intense supervision, so they choose more hidden real earnings management to obtain market or political interests.

5.3.2.3 Group analysis according to the degree of marketization

In regions with a high degree of marketization, environmental regulation has a more significant inhibitory effect on enterprises' upward accrued management. Regardless of the degree of marketization in the region where enterprises are located, environmental regulation promotes enterprises to carry out upward real earnings management. This result indicates that the upward real earnings management of the enterprise has nothing to do with the degree of marketization in the region where the enterprise is located.

Environmental protection tax inhibits upward real earnings management for firms in regions with a high degree of marketization. Generally, regions with a high degree of marketization have higher environmental protection requirements and intensity of environmental regulation. In this way, in places with a high degree of marketization, the environmental tax will have a more significant inhibitory effect on the real earnings management of enterprises.

For enterprises in regions with low marketization degrees, the joint effect of environmental regulation and environmental protection tax promotes upward real earnings management. In the regions with low marketization degree, the role of market mechanism is weaker, and non-market factors are more influential. By conducting upward real earnings management, enterprises can more effectively regulate the relationship between enterprises and the outside world to obtain more market and non-market interests.

5.3.2.4 Group analysis according to the level of government environmental protection investment

Environmental regulation inhibits enterprises in areas with low government investment in environmental protection from upward accrual earnings management but promotes upward real earnings management. In the regions with low government investment in environmental protection, the willingness of the government to regulate the environment is weaker. Although environmental regulation brings cost pressure to enterprises and enterprises face a certain degree of supervision, enterprises are strongly willing to show their business performance. Consequently, when accrual earnings management is inhibited, enterprises have more incentives for real earnings management.

Environmental taxes inhibit upward accrual earnings management of enterprises in areas with low government environmental protection investment and inhibit upward real earnings management of enterprises in areas with high government environmental protection investment. Regions with low environmental protection investment have weak government supervision and can choose accrual earnings management to reduce tax revenue. Regions with high marketization degrees can only choose covert real earnings management.

The combined effect of environmental regulation and environmental protection tax promotes upward real earnings management of firms in regions with high government investment in environmental protection. In regions with high government investment in environmental protection, the government pays more attention to environmental protection, and enterprises face more significant pressure from environmental regulation. The superposition of the dual cost pressure of environmental regulation and environmental protection tax promotes the increase of corporate financing demand, and the choice of upward real earnings management is conducive to realizing financing goals.

5.3.2.5 Group analysis according to whether the enterprise discloses the environmental protection concept

Regardless of whether the enterprise discloses the concept of environmental protection, environmental regulation inhibits the upward accrual earnings management of the enterprise, indicating that the inhibitory effect of environmental regulation on accrual earnings management has nothing to do with whether the enterprise discloses the concept of environmental protection. Environmental regulation promotes upward real earnings management of enterprises that do not disclose environmental protection concepts, indicating that enterprises that do not disclose environmental protection concepts receive low external attention and prefer to conduct upward real earnings management to obtain certain benefits.

The environmental protection tax inhibits the upward accrual earnings management of enterprises that do not disclose the environmental protection concept. In contrast, the environmental protection tax inhibits the upward real earnings management of enterprises that discloses the environmental protection concept. On the other hand, the environmental protection tax inhibits enterprises that disclose environmental protection concepts from conducting upward real earnings management. Environmental protection tax inhibits upward accrual earnings management of enterprises that do not disclose the environmental protection concept, which is consistent with the impact of environmental regulation. However, environmental protection tax inhibits the upward real earnings management of enterprises that disclose environmental protection concepts, which is inconsistent with environmental regulation promoting the upward real earnings management of enterprises that do not disclose environmental protection concepts. If environmental protection tax is regarded as incentive environmental regulation, it shows that different types of environmental regulation have different effects on enterprise earnings management. For example, enterprises may conduct downward earnings management to avoid taxes. Still, enterprises that disclose environmental protection concepts face more public attention and tend to conduct more hidden real earnings management.

The joint effect of environmental regulation and environmental protection tax promotes upward accrual earnings management of enterprises that do not disclose the concept of environmental protection. Whether the enterprise discloses the concept of environmental protection or not, the combined effect of environmental regulation and environmental protection tax promotes the upward real earnings management of the enterprise. As mentioned above, environmental protection tax inhibits the upward earnings management of enterprises that do not disclose environmental protection information, and the inhibitory effect of environmental regulation on the upward earnings management of enterprises has nothing to do with whether they disclose environmental protection information. In other words, environmental regulation and environmental protection tax have an inhibitory effect on the upward accrual earnings management of enterprises that do not disclose environmental protection concepts. Still, the joint effect of environmental regulation and environmental protection tax promotes the upward accrual earnings management of enterprises that do not disclose environmental protection concepts.

6 Conclusion and recommendations

6.1 Main conclusion

1) Environmental regulation promotes enterprises' upward real earnings management and is independent of the size of enterprises and the marketization degree of the region in which enterprises are located. Environmental regulation promotes the downward real earnings management of non-state-owned enterprises. State-owned enterprises, regions with less government investment in environmental protection, and enterprises with undisclosed environmental concepts are more inclined to carry out upward real earnings management.
2) Environmental regulation inhibits the accrual earnings management of enterprises to increase profits, and it has nothing to do with the nature of enterprises, the size of enterprises, and whether to disclose the concept of environmental protection. Enterprises in the regions with high marketization degrees and those in the regions with less government investment in environmental protection are less willing to manage accrual earnings to increase profits.
3) Environmental protection tax also inhibits the enterprises' profit-increasing accrual earnings management, which is independent of enterprise size and the marketization degree of the region where the enterprise is located. Non-state-owned

enterprises, enterprises in regions with less government investment in environmental protection, and enterprises without disclosing the concept of environmental protection have less willingness to manage accruals to increase profits.

4) The combined effect of environmental regulation and environmental protection tax promotes enterprises to carry out upward real earnings management, and it has nothing to do with whether to disclose the concept of environmental protection. Under the joint effect of environmental regulation and environmental protection tax, non-state-owned enterprises, large-scale enterprises, enterprises in areas with low marketization degree, and enterprises in areas with high government investment in environmental protection are more inclined to upward real earnings management.
5) The combined effect of environmental regulation and environmental protection tax promotes the accrual earnings management of enterprises, which is not related to the size of enterprises, the degree of marketization in the region where enterprises are located, and the amount of government investment in environmental protection. Under the joint effect of environmental regulation and environmental protection tax, state-owned enterprises and enterprises that do not disclose the concept of environmental protection are more inclined to carry out accrual earnings management to increase profits.

6.2 Recommendations

1) We should improve policies and regulations such as environmental regulation and environmental protection tax. Environmental regulation and environmental protection tax systems are essential policies and measures to achieve carbon peak and neutrality. We should not only constantly improve the system of environmental regulation, environmental protection tax, and other policies and regulations but also constantly improve the transparency of implementation of environmental regulation, environmental protection tax, and other policies and regulations. At the same time, we should also improve the market trading system of carbon emission rights and the enterprise environmental protection evaluation system, give full play to the role of the market mechanism, and encourage enterprises to innovate production mode and production technology.
2) We need to improve and give full play to the role of environmental protection tax in guiding, regulating, and motivating enterprises. Environmental protection tax is a means to promote the green production of enterprises. In response to the impact of COVID-19 in the past 3 years, preferential policies for environmental protection taxes have been implemented, such as deferred tax payments. These policies can not only help enterprises tide over difficulties but also avoid too much tax burden pressure that may strengthen the motivation of earnings management.
3) We need to develop unified standards for corporate environmental information disclosure. Enterprises do not disclose or selectively disclose environmental protection information, which makes it more difficult for the government to regulate or provides opportunities for enterprises that are more inclined to conduct earnings management (Li et al., 2022). At the same time, we need to make it mandatory for enterprises to disclose relevant environmental protection information, which is conducive to government supervision and improving enterprises' awareness of social responsibility.
4) We should further improve enterprises' business environment and market system. Enterprises conduct earnings management for certain motives, such as obtaining financing and reducing financing costs (Li et al., 2022), "crying poor" to obtain government subsidies, or operators to obtain higher salaries or other non-market interests. A sound business environment and market system are conducive to avoiding the transformation of these motives into corporate behaviors and can even eliminate part of the motives for earnings management.
5) We need to consider the combined effect of environmental regulation and environmental protection tax. Environmental regulation is mandatory, and environmental protection tax is an incentive. Environmental regulation may distort the optimal behavior of enterprises, which is supplemented by environmental taxation (Tanaka and Tanaka, 2022). We need to pay close attention to the status of enterprises in real time, rationally use the combination of mandatory regulation and incentive regulation, give full play to the role of policy tools in guiding and supervising enterprises, and promote the sustainable and healthy development of enterprises.

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

SF, JY, and DX designed the research and wrote the manuscript. SF, ZC, and GY conducted data analysis and verification, modifying and finalizing the paper. All authors contributed to the article and approved the submitted version.

Conflict of interest

GY was employed by Xiamen Airlines Co Ltd.

The remaining 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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