



Does corporate climate risk promote climate response actions? Empirical evidence from China

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Abstract

As primary contributors to climate change, corporations face significant climate risk (CR) and are required to undertake various climate response actions (CRA). Understanding whether corporate CR promotes corporate CRA is crucial for achieving the Sustainable Development Goals. Using data from Chinese A-share listed companies spanning 2007–2022, the CR index was constructed through machine learning and text-mining methods, while the CRA index was developed across three dimensions: carbon emission reduction (CER), environmental protection (EP), and green innovation (GI). Subsequently, an industry–year fixed effects model was employed to examine the relationship between CR and CRA. Results indicate that corporate CR significantly enhanced CER and GI, whereas its effect on EP was statistically insignificant. The mechanism analysis suggests that the proportion of executives with overseas experience and financial expertise positively moderated the impact of CR on GI. Moreover, media attention significantly strengthened the positive effect of CR on CER and GI, whereas the moderating effects of market and legal environments were statistically insignificant. The heterogeneity analysis reveals that the effect of CR on CER was more pronounced in state-owned and labor-intensive corporations, while its influence on GI was stronger in privately-owned and technology-intensive corporations. These findings enrich the literature on corporate CR management and offer valuable insights for companies, investors, policymakers, and other stakeholders to address climate change.

Highlights

- Developed a corporate climate risk (CR) index using multi-source textual data.
- Found heterogeneous effects of CR on different types of climate response actions (CRA).
- Identified greenwashing behaviors in firms' environmental protection efforts.
- Examined how internal and external environments moderate CR's influence on CRA.
- Revealed that CR's impact on CRA varies across ownership and factor intensity types.

Keywords Climate risk · Climate response actions · Carbon emission reduction · Environmental protection · Green innovation

JEL classification D22 · Q54 · Q56

1 Introduction

Climate risk (CR) has emerged as a major global challenge, exerting significant threats to economic prosperity, social vitality, and ecological sustainability (Mora et al. 2022). Under the 2015 Paris Agreement on Climate Change, 197 countries committed to limiting the rise in global average temperature to less than 2 °C above pre-industrial levels (Rogelj et al. 2016). Additionally, United Nations member states adopted the 2030 Agenda for Sustainable Development, comprising 17 Sustainable Development Goals (SDGs), with the 13th goal addressing climate action. Corporate production and operational emissions have been identified as major drivers of climate change, and corresponding climate response actions (CRA) are vital for achieving the SDGs (Zhang and Li 2025). Accurate assessment of corporate CR and CRA, along with a clear understanding of their interrelationship, remains an urgent research priority.

Early research primarily assessed corporate CR through questionnaires and interviews. For instance, the Carbon Disclosure Project (CDP) has annually employed questionnaires to evaluate the physical CR of large corporations (Toukabri and Kalai 2024). Corporations were asked to select one of three responses: (1) “we believe the corporation faces physical CR”; (2) “we do not know”; (3) “we do not believe the corporation faces physical CR”. Similarly, Weinhofer and Busch (2013) integrated firms’ CDP questionnaire responses with interview data to evaluate the CR levels of electric power companies. However, the results derived from these measures are highly subjective, lack precise scaling, and exhibit questionable accuracy. To address these shortcomings, recent studies have increasingly adopted index-based approaches to measure corporate CR. For example, Deng et al. (2024) used the number of extreme high-temperature days, extreme low-temperature days, and extreme precipitation days in corporate locations as proxy indicators of CR. Liu et al. (2025) constructed a corporate CR index by calculating the frequency of four core terms: “high temperature”, “sea level rise”, “flood”, and “drought” appearing in the “Management Discussion and Analysis” sections of corporate annual reports. However, existing corporate CR indices exhibit two major limitations. First, CR is a broad concept encompassing not only the physical damage from extreme climate events, but also risks in achieving climate goals, such as technological transformation, market competition, and regulatory policy changes (Liu et al. 2024). Moreover, several studies have confirmed that compared with climate-related physical risks, transition and regulatory risks exert a stronger influence on firms’ formulation of climate response strategies (Ren et al. 2025; Jiao et al. 2025). Therefore, focusing solely on physical CR constrains the comprehensive assessment of corporate CR. Additionally, representing corporate CR using regional climate data ignores firm-level heterogeneity and fails to yield an independent and accurate measure of corporate CR.

Some researchers have assessed corporate CRA through questionnaires or reviews of sustainability reports, reporting that most firms have undertaken positive CRA. Kang et al. (2017) compiled a list of corporate CRA, examined corporations’ disclosure in corporate sustainability reports, and affirmed their efforts to address climate change. Based on a literature review, Toft and Rüdiger (2020) developed a mapping tool to test corporate CRA and applied it to three Danish energy firms. Through content analysis of sustainability reports and semi-structured interviews, the authors confirmed a wide range of corporate responses to climate change. However, these methods suffer from two major limitations.

First, the credibility of the questionnaire results and corporate sustainability reports remains uncertain. Impression management theory posits that corporate information disclosure often reflects opportunistic behavior (Merkl-Davies and Brennan 2007). Such behavior leverages information asymmetry between corporations and stakeholders, enabling corporations to manipulate sustainability reports to project a favorable corporate image. Second, corporations tend to disclose vague climate strategies rather than measurable performance outcomes (Wanhai et al. 2025). Therefore, these methods may inaccurately evaluate corporate CRA due to potential misrepresentation in disclosures. In summary, previous studies have not provided accurate or effective measures of corporate CR and CRA. Furthermore, although an increasing number of studies have explored the impact of CR on corporate credit, financial performance, debt decisions, bond returns, cash holdings, and investment (F. Zhao et al 2025; Arian and Naeem 2025; Jiang et al. 2025), few have examined its influence on CRA. Recognizing these research gaps, this study aims to explore three key questions: (1) How can corporate CR and CRA be accurately measured? (2) Does corporate CR promote CRA? (3) Which factors influence the transformation of corporations from facing CR to undertaking CRA? To address these questions, this study employed machine learning and text-mining methods to construct a corporate CR index, alongside a CRA index developed from multiple dimensions. Using Chinese A-share listed companies from 2007 to 2022 as research samples, this study examined their relationship through an industry-year fixed effects model. Building upon this, the study further explored the moderating roles of executive characteristics, the market and legal environment, and media attention within this relationship. To further investigate heterogeneity across firms, this study analyzed variations based on ownership structure and factor intensity. As one of the world's largest carbon emitters, Chinese corporations not only face heightened CR but also attract widespread international attention regarding the effectiveness of their CRA (Jiang et al. 2020). Examining how Chinese corporations respond to CR offers valuable insights for other high-carbon-emitting countries, particularly developing economies. These characteristics make China an ideal sample for understanding the relationship between CR and CRA. Compared with prior studies, the primary contributions of this study are as follows.

1. Theoretically, this study categorizes corporate CR into physical, market, and regulatory dimensions, highlights the diversity and effectiveness of CRA, and constructs a CRA index based on three dimensions: carbon emission reduction (CER), environmental protection (EP), and green innovation (GI). These frameworks enrich the existing literature on corporate CR management. Furthermore, the study offers a novel examination of the impact of corporate CR on CRA, reinforces their micro-level linkage, and provides new directions for future research.
2. Empirically, this research integrates various data sources and employs machine learning and text-mining methods to construct a Chinese corporate CR domain dictionary. This approach mitigates semantic inconsistencies arising from the direct application of English domain dictionaries and addresses the limitations of prior studies, which have predominantly focused on Western economies while neglecting the market and regulatory risks shaped by China's institutional context.
3. Practically, this study identifies corporate greenwashing in EP efforts. Furthermore, it examines the moderating roles of executive characteristics, market and legal

environment, and media attention in the relationship between corporate CR and CRA, and explores the heterogeneity of this relationship across corporations with different ownership structures and factor intensities. The findings offer valuable insights for national policymakers, enterprises, and stakeholders, facilitating progress toward the SDGs.

The remainder of this paper is structured as follows. Section 2 reviews the relevant theories and develops the research hypotheses. Section 3 describes models and variables. Section 4 presents the empirical results. Section 5 provides further discussion and comparative analysis. Section 6 concludes the study and offers policy recommendations. The research framework is illustrated in Fig. 1.

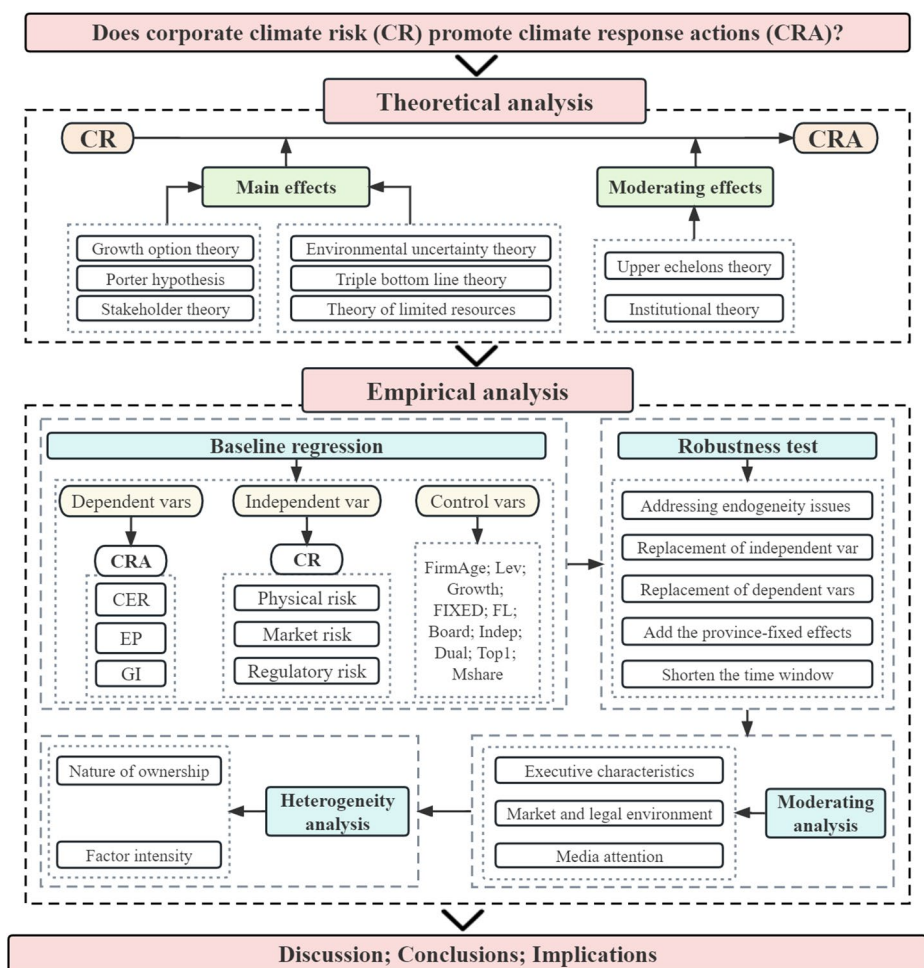


Fig. 1 Research framework

2 Literature review and hypothesis development

2.1 Corporate CR

As major contributors to climate change, corporations also face significant CR in their production and operational activities. Based on existing literature, corporate CR can be classified into three categories: physical, market, and regulatory risks (Elijido-Ten 2017; Sakhel 2017).

Physical risk denotes the threats posed by climate-related disasters such as floods, droughts, and hurricanes (Qian et al. 2024). These events may damage fixed assets, disrupt supply chain stability, and hinder resource accessibility, ultimately leading to financial losses (Guo and Li 2025). Market risk arises from changes in investor preferences, technological progress, and financial market dynamics due to climate change. For example, as climate awareness grows, investors increasingly incorporate corporate climate performance into investment decisions to mitigate potential risks (Z. Lu et al 2025). Regulatory risk stems from policies designed to address climate change. Increasing public and policy attention to climate change has intensified climate-related regulations, raising corporate production and investment costs and influencing financial disclosure practices and corporate reputations (Bingler et al. 2024; Jin and Wang 2025).

2.2 Corporate CRA

Although no consensus exists regarding the classification of corporate CRA, these actions are generally defined as corporate activities intended to mitigate climate change. In China, the government acts as the principal authority in climate governance and has promulgated numerous corporation-oriented climate response policies, which can be broadly classified into CER, EP, and GI (He et al. 2025; Zhu et al. 2025; Li and Lu 2025).

Excessive carbon dioxide emissions are widely recognized as a primary driver of climate change. As a major carbon emitter, China has consistently prioritized corporate CER and introduced various policy tools, including feed-in tariffs, green bond issuance, carbon pricing mechanisms, and Low-carbon pilot (Liu et al. 2020a, ; Solangi and Magazzino 2025). CER performance has frequently served as a proxy indicator for evaluating corporate CRA (Muchenje 2025). In addition, recognizing the role of ecosystem services in mitigating climate change, China introduced the policy requirement to “synergize the reduction of both pollution and carbon emissions”, mandating corporations to adopt EP practices that mitigate their adverse climate impact (Zhu and Wang 2024). The Chinese government has also enacted several policies to guide corporate EP, including the *Administrative Regulations on Levy and Use of Pollutant Discharge Fees* and the *Environmental Protection Tax Law*. In 2019, China released the *Guiding Opinions on Building a Market-Oriented Green Technological Innovation System*, marking the first official inclusion of corporate GI in a government policy document. Compared with traditional climate governance tools, GI not only fulfills government policy requirements by improving resource utilization, but also enables corporations to gain competitive advantages and access emerging market opportunities through innovation-driven product and service upgrades (Mirza et al. 2025; Khanra et al. 2022). Currently, GI has transcended its traditional role and is increasingly recognized as a core tool for corporations in achieving climate sustainability (Solangi et al. 2024).

2.3 The impact of corporate CR on CRA

2.3.1 Corporate CR will promote CRA

Frequent changes in climate conditions and policies underscore the CR uncertainty. Within this context, growth option theory views such uncertainty as an opportunity for growth, suggesting that corporations will actively invest in exploratory projects despite uncertain short-term returns (Berk et al. 1999). For example, interviews with 12 aviation-sector executives revealed that industry investment in decarbonization initiatives has increased to secure long-term market sustainability (Mohd Hasan Wong et al. 2024). Similarly, the study of 398 nonfinancial firms listed in the S&P 500 index found that CR encourages greater environmental expenditure, thereby enhancing their environmental innovation scores (Hamim and Mollah 2025).

In addition, climate response policies are expected to tighten as CR intensifies. According to the Porter hypothesis, well-designed environmental regulations can incentivize corporate innovation (Porter 1991). Therefore, under climate-related regulatory frameworks, corporations are more likely to achieve climate governance goals by enhancing their innovative capacity. For example, Zhang and Shi (2025) found that the implementation of the Environmental Protection Tax Law enhances corporate investment in EP and R&D, thereby improving environmental performance. Lyu et al. (2024) reported that central environmental inspections reduce carbon intensity by stimulating both the scale and quality of green technological innovation. Similarly, J. Lu et al. (2025) demonstrated that China's low-carbon city pilot policy stimulates corporate GI by raising stakeholder environmental awareness.

Another key driver of corporate action is interaction with various stakeholders, which facilitates the internalization of environmental externalities (Wang et al 2024a). Stakeholder theory posits that corporations maintain long-term viability by meeting stakeholder value expectations (Freeman et al. 2004). Prior research indicates that CR has attracted increasing attention from governments, media, and investors. Such attention compels corporations to take CRA to align with stakeholder expectations and mitigate adverse selection risks in commodity and capital markets (Kaplan and Levy 2025). For instance, Li et al. (2023) found that as stakeholder emphasis on ESG intensifies, firms increasingly prioritize GI to strengthen their standing among investors and other stakeholders. Similarly, Xie and Ying (2025) found that public negative sentiment toward climate change significantly promotes corporate green investment.

In summary, based on the growth option theory, the Porter hypothesis, and stakeholder theory, the paper proposes the following hypothesis:

H1 Corporate CR can significantly promote corporate CRA.

2.3.2 Corporate CR may not promote CRA

However, some scholars challenge the above perspectives. First, environmental uncertainty theory suggests that CR-induced uncertainty may cause corporations to adopt a wait-and-see approach toward CRA (Milliken 1987). For example, a survey of 100 of the world's largest greenhouse gas emitters revealed that although 89% of companies recognize CR, only 5.6% have implemented projects to mitigate them (Kouloukoui et al. 2019). Similarly,

L. Zhao et al. (2025) demonstrated that climate policy uncertainty hampers transportation enterprises' investment in low-carbon technologies and infrastructure, complicates long-term planning, and ultimately inhibits their carbon performance.

Additionally, the triple bottom line theory underscores the balanced consideration of corporations in economic, environmental, and social responsibility (Elkington 1994). CR disrupts corporate production, operations, and financial stability, thereby undermining this balance. Immediate economic pressures often divert corporate attention from long-term sustainability goals. For instance, Wang et al. (2023) found that to offset CR losses, companies often disregard ESG principles and instead favor high-carbon industries with lower costs and technological barriers, thereby weakening green governance and undermining corporate social responsibility.

Finally, although proactive CRA can provide a sustainable competitive advantage, it typically requires long-term commitment and substantial financial resources. Within this context, according to the theory of limited resources, corporations tend to allocate limited financial and human resources to short-term financial activities to mitigate climate-related shocks (Yin et al. 2024). For instance, Lohmann (2011) found that in response to extreme climate events, companies often shift their focus toward transactions involving equity and financial derivatives, accelerating corporate financialization. Similarly, Arian and Naeem (2025) found that in regions facing higher CR, firms are more likely to increase cash reserves and adopt conservative investment strategies. From this perspective, CR exerts a negative influence on corporate CRA, as the allocation of limited resources toward financial performance reduces investment in CRA.

Therefore, drawing on the environmental uncertainty theory, the triple bottom line theory, and the theory of limited resources, this paper proposes the following hypothesis:

H2 Corporate CR may not promote corporate CRA.

3 Research design

3.1 Model construction

In this study, an industry–year fixed effects model was employed, and Eqs. (1)–(3) were constructed to empirically examine the effect of corporate CR on CRA, including CER, EP, and GI. This model effectively controls for inherent cross-industry heterogeneity and time-varying shocks, thereby allowing for a more accurate estimation of the net effect of corporate CR on CRA. Currently, this approach has been widely applied in evaluating the effects of corporate CR on green transformation, operational resilience, and environmental responsibility (Tian et al. 2025; Fang 2024; Guo and Li 2025).

$$CER_{i,j,t} = a_0 + a_1 CR_{i,j,t} + a_2 Controls_{i,j,t} + \psi_j + \delta_t + \varepsilon_{i,j,t} \quad (1)$$

$$EP_{i,j,t} = b_0 + b_1 CR_{i,j,t} + b_2 Controls_{i,j,t} + \psi_j + \delta_t + \varepsilon_{i,j,t} \quad (2)$$

$$GI_{i,j,t} = \gamma_0 + \gamma_1 CR_{i,j,t} + \gamma_2 Controls_{i,j,t} + \psi_j + \delta_t + \varepsilon_{i,j,t} \quad (3)$$

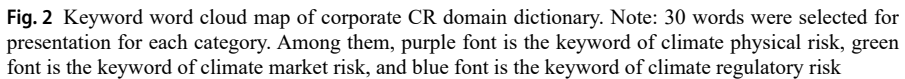
$CER_{i,j,t}$, $EP_{i,j,t}$, and $GI_{i,j,t}$ represent the CRA index of corporation i in industry j and year t , which are related to CER, EP, and GI, respectively. $CR_{i,j,t}$ signifies the CR index of corporation i in industry j and year t . $Controls_{i,j,t}$ represents a series of control variables, ψ_j denotes industry fixed effects, δ_t denotes time fixed effects, $\varepsilon_{i,j,t}$ represents the random error term. The standard error is uniformly clustered at the firm level. a_1 , b_1 , and γ_1 are the focal points of this study. Their economic implications are the impact of corporate CR on CER, EP, and GI, respectively.

3.2 Selection of variables

3.2.1 The independent variable

CR was the core independent variable, constructed using a combination of machine learning and text-mining methods. This approach allows for a more objective and comprehensive assessment of corporate CR, with the advantages of low cost and scalability. It has been widely applied to evaluate corporate disclosures on climate risk (Sautner et al. 2023b), innovation (Hua and Chen 2025), and environmental performance (Wang and Wang 2025). The construction of the CR index proceeded as follows.

- (1) Corpus selection. As mentioned in Section 2.1, corporate CR was categorized into physical, market, and regulatory risks. Drawing on existing literature and China's institutional context, official statistical publications, news reports, policy documents, and corporate disclosures were selected as the corpora for CR analysis (texts, selection reasons, and data sources are provided in Supplementary Table S1).
- (2) Custom dictionary loading. In text mining, loading a domain dictionary before segmentation prevents the mis-segmentation of professional terms. Following previous studies (Zhang 2024; Guo and Yong 2023; Du et al. 2023), existing CR domain keywords were integrated and deduplicated, yielding a custom dictionary containing 278 keywords.
- (3) Word weighting. After loading the custom dictionary and stop-word list, the Jieba segmentation tool was employed to preprocess the corpus and remove stop words. Subsequently, the Term Frequency-Inverse Document Frequency algorithm was applied to calculate word weights, and the top 30 words from each corpus were selected as candidate terms for the CR domain dictionary.
- (4) Manual screening. Three domain experts independently reviewed the candidate terms. Words unanimously deemed relevant to corporate CR were retained, while disagreements were resolved by a fourth reviewer. This process yielded 285 keywords. The manually screened keywords were then merged with the existing domain keywords, and duplicates were removed. Finally, the final corporate CR domain dictionary, consisting of 497 keywords, was established (see Fig. 2).
- (5) Corporate CR index calculation. The final domain dictionary was incorporated as a custom dictionary, and the corporate annual reports were segmented and filtered for stop words. The frequency of each keyword in corporate annual reports was then computed,



Comparison with existing research is essential to demonstrate the validity of the corporate CR index constructed in this study. Fig. 3 presents the temporal trend and distribution characteristics of corporate CR. As shown in Fig. 3 (a), corporate CR exhibited an upward trend, with three notable increases during 2007–2008, 2014–2015, and post–2020. These surges coincided with the introduction of major regulatory policies in China, including the *Notice on Regulation of Information Disclosure by Listed Companies and Behavior of Relevant Parties*, the *Environmental Protection Law of the People's Republic of China*, and the *Guidance Regarding Disclosure Related to Climate Change*. Each of these policies required corporations to enhance the quality and transparency of their climate-related disclosures. This alignment validates the rationality of the CR index constructed in this study. Fig. 3 (b) and (c) depict the heterogeneity of corporate CR across different industries and regions, respectively (industry categories and codes are listed in Supplementary Table S2). As illustrated in Fig. 3(b), corporations in Category D exhibited the highest levels of CR, followed by those in Category B, while firms in Categories K and S demonstrated the lowest CR levels. This industrial distribution is consistent with the reality that high-carbon sectors typically face stronger climate-related transition and regulatory pressures (Zhang et al. 2022), and aligns with the findings of Sautner et al. (2023a), thereby further supporting the reliability of the constructed CR index. Fig. 3 (c) shows that corporations located in Western China displayed significantly higher CR levels. This finding aligns with prior research demonstrating that, due to fragile ecosystems and relatively less-developed economies, western regions face heightened climate-related threats (Zhang et al 2025). Collectively, these empirical patterns validate both the rationality and effectiveness of the CR index proposed in this study.

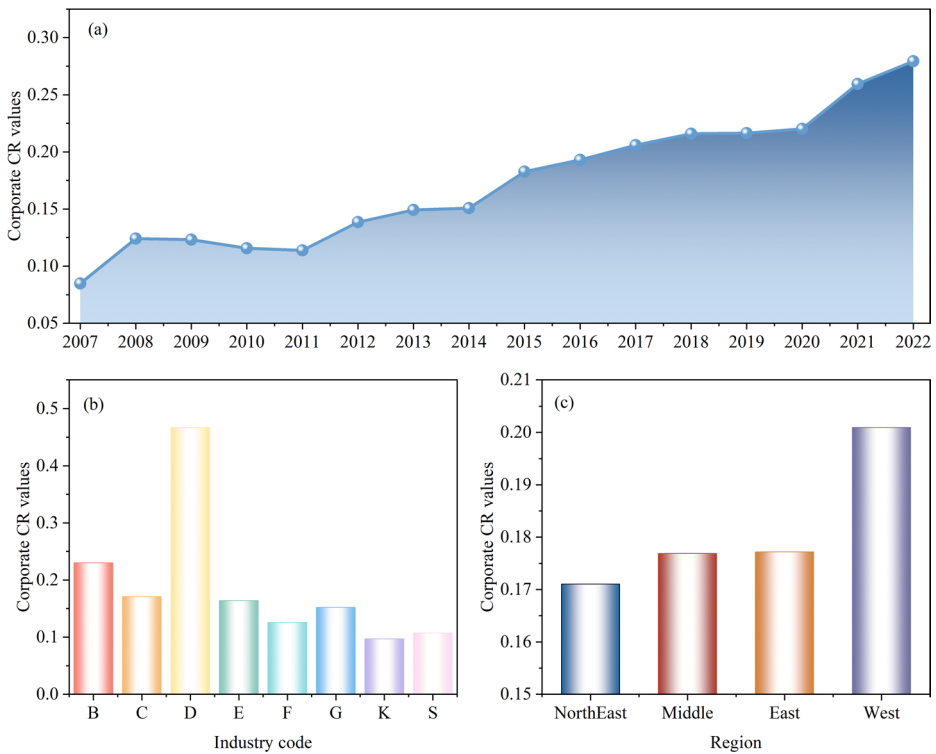


Fig. 3 Corporate CR index. (a) Temporal trend of the average corporate CR from 2007 to 2022. (b) Industry distribution of average corporate CR. (c) Regional distribution of average corporate CR. Fig. 3.

3.2.2 The dependent variable

CRA served as the dependent variable and was classified into three categories: CER, EP, and GI. Following prior studies, CER was measured by the logarithm of operating income per unit of carbon emissions (Li and Li 2023); EP was proxied by the logarithm of operating revenue per unit of sewage charge (Yu et al. 2019); and GI was calculated by the logarithm of one plus the number of green patent applications (Tian et al. 2024). Higher values of these three indicators indicate a stronger corporate CRA.

Fig. 4 illustrates the average values of CER, EP, and GI for Chinese corporations from 2007 to 2022. As shown in Fig. 4, all three indicators exhibited an overall upward trend, though their growth patterns varied significantly. Among them, GI displayed a steady and substantial increase, with an average growth rate of 9.831%. By contrast, the average annual growth rates of CER and EP were significantly lower, 0.012% and 0.010%, respectively, and exhibited considerable volatility. This divergence can be attributed to structural and institutional constraints inherent in traditional forms of CRA, such as CER and EP. Unlike GI, CER and EP improvements often depend on fundamental adjustments to the energy structure, industrial processes, and asset configurations. These adjustments require long-term capital commitments and systemic transformation, making short-term performance enhancement difficult to achieve (S. Wang et al 2024a, , ,).

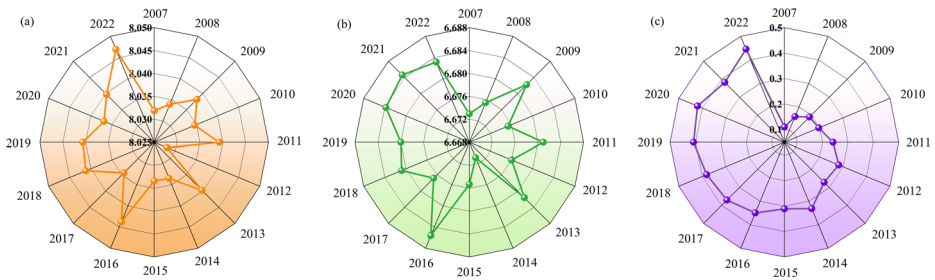


Fig. 4 Temporal trend of the average corporate CRA from 2007 to 2022. **(a)** Temporal trend of corporate CER. **(b)** Temporal trend of corporate EP. **(c)** Temporal trend of corporate GI.

3.3 Control variables

Drawing on existing research (Kouloukoui et al. 2020; Fang 2024), firm-level variables potentially influencing corporate CRA were selected as control variables. These variables included firm listing age, leverage level, the growth rate of business revenue, the proportion of fixed assets, financial leverage, board size, independent director share, duality, share proportion of the largest share holder, and management shareholding ratio.

3.4 Sample and data source

A-share listed corporations in Shanghai and Shenzhen from 2007 to 2022 were selected as the research sample. The data collection and preprocessing were conducted as follows: (1) corporations in the financial industry were excluded; (2) corporations with ST, *ST, and PT were excluded; (3) corporations with missing data on key variables were excluded; (4) missing values were addressed using linear interpolation; and (5) all continuous variables were winsorized at the 1% level. Finally, a total of 22,300 data were obtained. This study utilized multiple data sources. Textual data used to construct the corporate CR index were collected from the China Meteorological Administration (<https://www.cma.gov.cn/>), Ministry of Ecology and Environment of China (<https://www.mee.gov.cn/>), WiseSearch database (<https://wiseneeds.wisers.net/>), Chinese government website (<https://www.gov.cn/>), and Cninfo website (<http://www.cninfo.com.cn/new/index>). Corporate-level financial data were obtained from the China Stock Market and Accounting Research (CSMAR) database (<https://data.csmar.com/>) and China Research Data Service Platform (CNRDS) (<https://www.cnrd.com/>). The construction of the corporate CR index was performed in Python 3.13, while all econometric analyses were conducted in Stata 17.0. A summary of all variables is provided in Table 1.

4 Empirical results

4.1 Descriptive statistics

Table 2 provides the descriptive statistics for the variables. The mean value of CER was 8.037 with a relatively small standard deviation (0.145), indicating that most corporations

Table 1 Descriptive statistics of variables

No.	Variables	Acronyms	Descriptions	Units
1	Carbon emission reduction	CER	The logarithm of operating income per unit of carbon emissions	yuan/ton
2	Environmental protection	EP	The logarithm of operating income per unit of sewage charges	—
3	Green innovation	GI	The logarithm of one plus the total number of green patent applications	piece
4	Climate risk	CR	Frequency of keywords related to CR/Total length of the corporate annual report, multiplied by 100	—
5	Firm listing age	FirmAge	The logarithm of one plus the number of years since the company's establishment	year
6	Leverage level	Lev	Total liabilities at the end of the year/Total assets at the end of the year	—
7	Growth rate of business revenue	Growth	(Current year's operating income/Previous year's operating income)–1	—
8	The proportion of fixed assets	Fixed	Net fixed assets/Total assets	—
9	Financial leverage	FL	Change rate of earnings per share of common shares/Change rate of earnings before interest and tax	—
10	Board size	Board	The logarithm of the total number of board members	person
11	Independent director shares	Indep	Number of independent directors/Number of directors	—
12	Duality	Dual	Dummy variable, 1 for the same person as the chairman and managing director; 0 if not the same person	—
13	Share proportion of the largest shareholder	Top1	Shareholding of the largest shareholder/The total shares of the firm	—
14	Management shareholding ratio	Mshare	The number of shares held by directors, supervisors, and senior executives/The number of total equity	—

Table 2 Summary statistics

Variable	Observations	Mean	Std. dev.	Min	Max
CER	22,300	8.037	0.145	3.883	8.643
EP	22,300	6.680	0.146	2.120	7.333
GI	22,300	0.321	0.755	0.000	6.616
CR	22,300	0.181	0.163	0.000	1.757
FirmAge	22,300	2.866	0.358	0.693	3.611
Lev	22,300	0.455	0.198	0.027	0.908
Growth	22,300	0.174	0.400	–0.658	4.024
FIXED	22,300	0.248	0.167	0.002	0.769
FL	20,300	1.381	1.151	–1.982	11.549
Board	22,300	2.153	0.194	1.609	2.708
Indep	22,300	0.372	0.053	0.250	0.600
Dual	22,300	0.222	0.416	0.000	1.000
Top1	22,300	0.363	0.148	0.081	0.758
Mshare	22,300	0.095	0.175	0.000	0.706

Std. Dev refers to the standard deviation of the variable

exhibited comparable levels of CER. EP displayed a similar pattern, with a mean of 6.680 and a standard deviation of 0.146. In contrast, GI exhibited markedly higher volatility, with a standard deviation (0.755) exceeding its mean (0.321), revealing substantial disparities in corporate engagement in GI. The mean CR value was 0.181, ranging from nearly zero to 1.757, reflecting pronounced differences in CR among corporations. Supplementary Table S3 reports the variance inflation factors (VIF) of the variables. The maximum VIF was below 1.5, while the average VIF was 1.16, confirming that multicollinearity was not a concern in this study.

4.2 Baseline regression

Table 3 reports the estimation results for Eqs. (1)–(3). As shown in Column (1), CR significantly promoted CER at the 5% significance level, with a 1% increase in CR corresponding to a 0.014% increase in CER. Columns (2) illustrates that although the coefficient of CR on EP was positive ($b_1 = 0.007$), it was statistically insignificant ($p = 0.302$). In column (3), CR exerted a significantly positive effect on GI ($p < 0.01$), with a 1% increase in corporate CR associated with a 0.583% increase in GI. Overall, these results indicate that corporate

Table 3 Benchmark regression

	(1)	(2)	(3)
	CER	EP	GI
CR	0.014** (0.007)	0.007 (0.007)	0.583*** (0.092)
FirmAge	0.002 (0.004)	0.003 (0.004)	−0.096** (0.046)
Lev	−0.008 (0.006)	−0.005 (0.007)	0.538*** (0.077)
Growth	0.007** (0.003)	0.007** (0.003)	−0.045*** (0.011)
FIXED	−0.006 (0.008)	−0.005 (0.008)	−0.423*** (0.101)
FL	0.002*** (0.001)	0.003*** (0.001)	−0.012* (0.007)
Board	0.013** (0.005)	0.011* (0.006)	0.416*** (0.096)
Indep	0.033 (0.022)	−0.004 (0.023)	0.952*** (0.279)
Dual	−0.003 (0.003)	−0.001 (0.003)	−0.010 (0.029)
Top1	−0.012 (0.007)	−0.003 (0.008)	0.222** (0.099)
Mshare	0.011* (0.007)	0.010 (0.007)	−0.0004 (0.065)
Constant	7.994*** (0.021)	6.644*** (0.022)	−0.954*** (0.310)
Industry FE	YES	YES	YES
Year FE	YES	YES	YES
Cluster	Firm	Firm	Firm
Adj. R ²	0.259	0.237	0.786

In all tables, standard errors in parentheses, * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$

CR significantly promoted CRA related to CER and GI, but its effect on EP was not statistically significant. This finding partially supports H1 and H2, suggesting that CR stimulates corporations to undertake certain types of CRA.

4.3 Addressing endogeneity issues

To address potential endogeneity arising from omitted variables and reverse causality, the two-stage least squares (2SLS) estimation was employed. Following Z. Wang et al. (2024a) the average CR of other corporations within the same industry and year was used as an instrumental variable (IV). Regarding relevance, corporate CR tends to exhibit strong industry-level cohort effects; that is, the CR levels of other corporations within the same industry significantly influence the CR of the focal corporation. For exogeneity, the CR of other corporations in the same industry is unlikely to directly influence the focal corporation's CRA. Thus, the selected IV satisfies both the correlation and exogeneity assumptions.

Table 4 presents the results of the 2SLS estimation. Column (1) reports the first-stage regression results. The estimated coefficient of the IV was 0.481 and statistically significant at the 1% level, indicating a strong correlation with CR. The Kleibergen-Paap LM statistic (80.44) rejected the hypothesis of insufficient IV identification at the 1% significance level. Moreover, the Cragg-Donald Wald F statistic (603.12) exceeded the critical value of the Stock-Yogo weak IV identification test at the 10% significance level, rejecting the weak instrumental variable hypothesis. Thus, the selected IV was appropriate. Columns (2)–(4) report the second-stage regression results of CR on CER, EP, and GI, respectively. The coefficients suggest that corporate CR exerted a significantly positive effect on CER and GI at the 5% level, whereas its effect on EP remained statistically insignificant ($p = 0.124$). Overall, the 2SLS findings were consistent with the baseline results, reinforcing the conclusion that corporate CR significantly promoted CER and GI, while its influence on EP was not significant.

4.4 Robustness test

To ensure the robustness of the benchmark regression results, four additional tests were conducted.

First, the independent variable was replaced. As CR embodies both threat and opportunity dimensions, the baseline CR index captures only the overall intensity of corporate CR without distinguishing its semantic polarity. To focus on the threat-related CR, a negative climate risk index (NegCR) was constructed, defined as the proportion of negatively oriented CR keyword frequencies to the total length of the corporate annual report. The construction process of the NegCR indicator is presented in Supplementary 4.4, and the regression results are displayed in Table 5. As reported in Table 5, the estimated coefficients of NegCR on CER and GI were 0.043 and 1.773, respectively, and statistically significant at the 5% and 1% level. Column (2) presents that although NegCR promoted EI (coefficient = 0.022), this effect was not significant ($p = 0.302$).

Second, the dependent variables were replaced. Following prior studies, alternative measures were introduced: the logarithm of operating income per unit of energy consumption (OIperEC) (Hoffmann and Busch 2008), operating income per unit of environmental pro-

Table 4 Regression results of 2SLS

	(1)	(2)	(3)	(4)
	CR	CER	EP	GI
CR		0.082** (0.041)	0.064 (0.042)	0.444** (0.220)
IV	0.481*** (0.020)			
FirmAge	-0.023*** (0.003)	0.002 (0.004)	0.002 (0.004)	-0.117*** (0.019)
Lev	0.086*** (0.006)	-0.014** (0.007)	-0.011 (0.007)	0.551*** (0.036)
Growth	0.004* (0.002)	0.006** (0.002)	0.006** (0.002)	-0.046*** (0.013)
FIXED	0.131*** (0.007)	-0.014 (0.009)	-0.011 (0.009)	-0.443*** (0.048)
FL	0.002** (0.001)	0.001 (0.001)	0.002** (0.001)	-0.012** (0.005)
Board	0.018*** (0.006)	0.009 (0.006)	0.008 (0.006)	0.401*** (0.032)
Indep	-0.069*** (0.021)	0.043** (0.021)	0.008 (0.021)	0.891*** (0.112)
Dual	0.001 (0.002)	-0.001 (0.002)	0.001 (0.002)	-0.01 (0.013)
Top1	0.036*** (0.007)	-0.015** (0.007)	-0.008 (0.007)	0.202*** (0.037)
Mshare	-0.020*** (0.006)	0.007 (0.006)	0.005 (0.006)	-0.002 (0.033)
Constant	-0.006 (0.022)	8.002*** (0.022)	6.646*** (0.022)	-1.070*** (0.116)
Industry FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
KP-LM		80.44***	80.44***	80.44***
CD-F		603.12	603.12	603.12

KP-LM refers to the Kleibergen-Paap LM statistic, and CD-F refers to the Cragg-Donald Wald F statistic

Table 5 Replacement independent variable for robustness tests

	(1)	(2)	(3)
	CER	EP	GI
NegCR	0.043** (0.021)	0.022 (0.021)	1.773*** (0.283)
Constant	8.001*** (0.020)	6.648*** (0.022)	-0.542* (0.307)
Controls	YES	YES	YES
Industry FE	YES	YES	YES
Year FE	YES	YES	YES
Province FE	YES	YES	YES
Cluster	Firm	Firm	Firm
Adj. R ²	0.285	0.266	0.726

tection investment (OIperEPI) (Wang and Jia 2020), and the logarithm of one plus the total number of green innovation patent applications (GreenInv) (Jia et al. 2025), as proxies for CER, EP, and GI, respectively. The results, presented in Table 6, indicate that CR significantly promoted OIperEC and GreenInv (both significant at the 1% level), while its effect on OIperEPI remained insignificant ($p = 0.205$).

Third, province-fixed effects were incorporated to control the potential heterogeneity across regions (see Table 7). The results show that after including province-, industry-, and time-fixed effects, the estimated coefficients of CR on CER (0.013) and GI (0.598) remained positive and statistically significant at the 5% and 1% levels, respectively, whereas the coefficient for EP remained insignificant ($p = 0.357$).

Fourth, the time window was shortened. Given the potential impact of COVID-19, data from 2020 to 2021 were excluded, and regressions were re-estimated using the remaining sample (see Table 8). Columns (1) and (3) indicate that the coefficients of CR on CER and GI were 0.014 and 0.509, respectively, both statistically significant. However, the coefficient (0.007) for EP remained insignificant ($p = 0.402$).

In summary, across all four robustness tests, the findings consistently demonstrate that corporate CR significantly promoted CER and GI, whereas its effect on EP remained statistically insignificant. These results confirm the robustness and stability of the benchmark regression outcomes.

Table 6 Replacement dependent variables for robustness tests

	(1)	(2)	(3)
	OIperEC	OIperEPI	GreenInv
CR	1.096*** (0.155)	1.457 (1.149)	0.409*** (0.073)
Constant	7.984*** (0.463)	-0.448 (3.741)	-0.928*** (0.261)
Controls	YES	YES	YES
Industry FE	YES	YES	YES
Year FE	YES	YES	YES
Cluster	Firm	Firm	Firm
Adj. R ²	0.342	0.306	0.585

Table 7 Adding province-fixed effects for robustness tests

	(1)	(2)	(3)
	CER	EP	GI
CR	0.013** (0.007)	0.006 (0.007)	0.598*** (0.091)
Constant	7.998*** (0.021)	6.644*** (0.022)	-0.953*** (0.303)
Controls	YES	YES	YES
Industry FE	YES	YES	YES
Year FE	YES	YES	YES
Province FE	YES	YES	YES
Cluster	Firm	Firm	Firm
Adj. R ²	0.413	0.398	0.951

Table 8 Shortened time window for robustness tests

	(1)	(2)	(3)
	CER	EP	GI
CR	0.014* (0.008)	0.007 (0.008)	0.509*** (0.096)
Constant	7.986*** (0.024)	6.627*** (0.025)	-0.958*** (0.320)
Controls	YES	YES	YES
Industry FE	YES	YES	YES
Year FE	YES	YES	YES
Cluster	Firm	Firm	Firm
Adj. R ²	0.296	0.256	0.772

4.5 Moderating mechanism analysis

A deeper understanding of the factors influencing the transition of corporations from facing CR to taking CRA is essential for formulating targeted policy recommendations. Drawing on previous studies, the moderating factors affecting the impact of CR on CRA can be classified into two categories: internal environmental factors and external environmental factors (Elsayih et al. 2021; Ma et al. 2024; Tavakolifar et al. 2021a). The former primarily refers to executive characteristics, whereas the latter pertains to the institutional environment in which corporations operate, encompassing both formal and informal components. The formal institutional environment primarily includes market mechanisms and legal regulatory frameworks, while the informal institutional environment mainly involves media supervision that influences corporate behavior.

4.5.1 Executive characteristics

Upper echelons theory suggests that organizational decision-making and performance are significantly influenced by executive characteristics (Hambrick 2007). For instance, numerous studies have documented a positive relationship between the proportion of female directors and the initiative and quality of corporate climate information disclosure (McGuinness et al. 2017). This may stem from women's tendency to uphold stronger ethical values and exhibit a heightened sense of responsibility (Galletta et al. 2022). Additionally, some scholars have found that executives with overseas backgrounds are more inclined to make strategic choices that promote corporate social responsibility. Such behavior may result from exposure to sustainability norms in developed countries, which leads these executives to internalize climate governance as a personal value and to better appreciate the importance of proactive CRA (Marquis and Tilcsik 2013). Several studies have also demonstrated the key role of executive expertise in corporate strategic decision-making (Orens and Reheul 2013). For instance, Li et al. (2019) found that executives' financial expertise is positively associated with the quality of corporate environmental information disclosure. Similarly, Harjoto et al. (2018) reported that executives possessing professional knowledge in finance, consulting, law, or management are more capable of making sound investment decisions.

In summary, this study assumed that executive background characteristics would influence the transition of corporations from facing CR to implementing CRA. Accordingly, the moderating effects of three executive attributes were examined: the proportion of female executives (Female), the proportion of executives with overseas education (Oversea), and

the proportion of executives with financial expertise (Fin). To empirically test these moderating effects, Eqs. (4)–(6) were estimated.

$$CER(GI)_{i,j,t} = d_0(') + d_1(') CR_{i,j,t} + d_2(') Female_{i,j,t} + d_3(') CR_{i,j,t} * Female_{i,j,t} + d_4(') Controls_{i,j,t} + \psi_j + \delta_t + \varepsilon_{i,j,t} \quad (4)$$

$$CER(GI)_{i,j,t} = e_0(') + e_1(') CR_{i,j,t} + e_2(') Oversea_{i,j,t} + e_3(') CR_{i,j,t} * Oversea_{i,j,t} + e_4(') Controls_{i,j,t} + \psi_j + \delta_t + \varepsilon_{i,j,t} \quad (5)$$

$$CER(GI)_{i,j,t} = f_0(') + f_1(') CR_{i,j,t} + f_2(') Fin_{i,j,t} + f_3(') CR_{i,j,t} * Fin_{i,j,t} + f_4(') Controls_{i,j,t} + \psi_j + \delta_t + \varepsilon_{i,j,t} \quad (6)$$

Columns (1) and (2) of Table 9 indicate that the proportion of female executives exerted a positive moderating effect on the transition from CR to CER ($d_3 = 0.035$) and GI ($d'_3 = 0.069$); however, these effects were not statistically significant ($p = 0.533$ and $p = 0.915$, respectively). Columns (3) and (4) show that while the moderating effect of executives with overseas backgrounds on CER was insignificant ($p = 0.406$), it positively moderated the impact of CR on GI at the 5% significance level ($e_3 = 0.285$). Column (5) illustrates

Table 9 The moderating effect of executive characteristics on the impact of corporate CR on CRA

	Female		Oversea		Fin	
	(1)	(2)	(3)	(4)	(5)	(6)
	CER	GI	CER	GI	CER	GI
CR	0.014** (0.007)	0.580*** (0.092)	0.015** (0.007)	0.590*** (0.094)	0.015** (0.007)	0.582*** (0.093)
Female	0.022** (0.011)	0.351*** (0.101)				
CR*Female	0.035 (0.056)	0.069 (0.640)				
Oversea			0.016 (0.010)	0.295 (0.736)		
CR*Oversea			0.053 (0.064)	0.285** (0.129)		
Fin					0.006 (0.011)	0.022 (0.124)
CR*Fin					−0.066 (0.077)	0.624*** (0.165)
Constant	8.000*** (0.021)	−0.791** (0.311)	7.998*** (0.021)	−0.863*** (0.319)	8.007*** (0.021)	−0.866*** (0.323)
Controls	YES	YES	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Cluster	Firm	Firm	Firm	Firm	Firm	Firm
Adj. R ²	0.281	0.807	0.268	0.774	0.258	0.757

that executives with financial expertise negatively moderated the relationship between CR and CER ($\beta_3 = -0.066$), though the effect was not statistically significant ($p = 0.395$). In contrast, Column (6) demonstrates that executives with financial expertise significantly enhanced the transition from CR to GI ($\beta'_3 = 0.624, p < 0.01$).

4.5.2 Market and legal environment and media attention

Institutional theory posits that the formal institutional environment, defined by the legal and market regulatory framework, exerts external constraints on corporate decision-making. Simultaneously, corporations adjust their development strategies in response to changes in the legal environment (DiMaggio and Powell 1983). For example, Yan et al. (2023) found that operating in regions with stronger legal frameworks tends to achieve higher ESG performance. In contrast, in areas where market legal systems are underdeveloped, the ambiguous boundaries of government authority and the distorted allocation of factor markets hinder the effective reward of corporate social responsibility. Consequently, corporate executives often prioritize short-term interests, resulting in lower ESG outcomes. Building on Guo et al. (2023), this study employed the sub-index “Intermediary Organization Development and Legal System Environment” from the Marketization Index of China’s Provinces (<https://cmi.ssap.com.cn/>) (MLE) as a proxy for the formal institutional environment. The regression model incorporating the moderating effect of the MLE was presented in Equation (7).

$$\begin{aligned} CER(GI)_{i,j,t} = & g_0(') + g_1(') CR_{i,j,t} + \\ & g_2(') MLE_{i,j,t} + g_3(') CR_{i,j,t} * MLE_{i,j,t} \\ & + g_4(') Controls_{i,j,t} + \psi_j + \delta_t + \varepsilon_{i,j,t} \end{aligned} \quad (7)$$

Independent of the legislature, judiciary, and administration, the media, known as “the fourth estate,” serves as an essential supplementary mechanism for supervising capital markets and plays a vital role in external corporate governance (Dyck et al. 2008). Existing studies widely recognize that media attention primarily influences corporate CRA by shaping corporate reputation. For instance, Li et al. (2018) demonstrated that the legitimacy pressures associated with climate response encourage firms under media exposure to promote GI as a means of enhancing corporate reputation and reducing the risk of adverse investor selection. Tavakolifar et al. (2021b) found that increased media exposure attracts heightened public attention, compelling firms to place greater emphasis on reputation management and strengthen their commitment to climate responsibility. Considering the advantages of online media over traditional media in the digital era, this study adopted the logarithm of one plus the total number of financial news articles related to each company in the CNRDS database (<http://www.cnrds.com>), as a proxy for media attention to measure the informal institutional environment, denoted as “Media” (Wu and Zheng 2021). The regression model incorporating the moderating effect of media attention was presented in Eq. (8).

$$\begin{aligned} CER(GI)_{i,j,t} = & h_0(') + h_1(') CR_{i,j,t} + \\ & h_2(') Media_{i,j,t} + h_3(') CR_{i,j,t} * Media_{i,j,t} \\ & + h_4(') Controls_{i,j,t} + \psi_j + \delta_t + \varepsilon_{i,j,t} \end{aligned} \quad (8)$$

Columns (1) and (2) of Table 10 present the moderating effects of the MLE on the relationship between corporate CR and CRA. The results indicate that MLE exerted a positive but statistically insignificant moderating effect on the impact of CR on CER ($g_3 = 0.029$, $p = 0.457$), while its moderating effect on the relationship between CR and GI was negative and also not statistically significant ($g_3' = -0.051$, $p = 0.257$). Column (3) of Table 10 shows that media attention significantly strengthened the positive effect of CR on CER ($h_3 = 0.012$, $p = 0.022$). Similarly, as shown in Column (4), media attention also exerted a positive moderating effect on the effect of CR on GI ($h_3' = 0.168$, $p = 0.050$).

4.6 Heterogeneity analysis

Many studies have demonstrated that corporations differ substantially in their engagement with social responsibility depending on their intrinsic characteristics (Pan et al. 2021; Niu et al. 2023). To further investigate the heterogeneous effects of CR on CRA, this study explored such impacts from two perspectives: ownership structure and factor intensity.

4.6.1 Nature of ownership

To examine the potential heterogeneity in the impact of corporate ownership on the relationship between CR and CRA, corporations were classified as either state-owned (SOEs) or privately-owned (POEs), with a corresponding dummy variable SOE. SOEs were assigned a value of 1, and POEs a value of 0. The regression results are presented in Table 11.

Columns (1) and (3) of Table 11 report the effect of CR on CER of SOEs and POEs, respectively. As shown in Column (1), CR significantly promoted CER among SOEs ($p < 0.01$), with the marginal effect of CR on CER among these firms being approximately twice its global marginal effect (0.029 vs. 0.014). Although CR also exhibited a positive effect on CER among POEs (see Column (3)), this relationship was statistically insignificant ($p = 0.890$) and notably weaker than that observed for SOEs (0.001 vs. 0.029). Columns (2)

Table 10 The moderating effect of institutional environment on the impact of corporate CR on CRA

	MLE		Media	
	(1)	(2)	(3)	(4)
	CER	GI	CER	GI
CR	0.014** (0.007)	0.542*** (0.087)	0.014** (0.007)	0.533*** (0.089)
MLE	0.005 (0.007)	0.014*** (0.004)		
CR*MLE	0.029 (0.039)	0.051 (0.045)		
Media			0.002 (0.001)	0.138*** (0.022)
CR*Media			0.012** (0.005)	0.168* (0.086)
Constant	7.996*** (0.021)	-0.848*** (0.311)	8.002*** (0.022)	-0.377 (0.286)
Industry FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Cluster	Firm	Firm	Firm	Firm
Adj. R ²	0.259	0.822	0.282	0.808

Table 11 Heterogeneity test based on corporate ownership nature

	SOE=1		SOE=0	
	(1)	(2)	(3)	(4)
	CER	GI	CER	GI
CR	0.029*** (0.011)	0.412*** (0.135)	0.001 (0.009)	0.720*** (0.125)
Constant	7.984*** (0.034)	-1.194** (0.484)	8.008*** (0.027)	-0.349 (0.409)
Industry FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Cluster	Firm	Firm	Firm	Firm
Adj. R ²	0.455	0.983	0.293	0.706

and (4) of Table 11 present the effects of CR on GI for SOEs and POEs, respectively. The estimated coefficients were 0.412 for SOEs and 0.720 for POEs, both significant at the 1% level. These results indicate that CR significantly promoted GI in both ownership types. However, compared to the global marginal effect of CR on GI (0.538), its promotional effect on POEs was more pronounced, suggesting that POEs tend to respond more actively to climate-related challenges through innovation-driven strategies.

4.6.2 Factor intensity

Following Yin et al. (2018), corporations were further classified into labor-intensive, technology-intensive, and capital-intensive categories based on factor intensity. The impact of CR on CRA was then examined separately across these three corporate types, with the regression results presented in Table 12.

Columns (1), (3), and (5) of Table 12 report the effect of CR on CER among firms with different factor intensities. Specifically, CR significantly promoted CER among labor-intensive corporations ($p = 0.098$), where a 1% increase in CR corresponded to a 0.022% rise in CER, exceeding the global marginal effect of CR on CER (0.014). Although CR also exerted positive effects on CER in technology-intensive (coefficient = 0.010) and capital-intensive (coefficient = 0.019) corporations, these effects were not statistically significant ($p = 0.433$ and $p = 0.129$, respectively). Columns (2), (4), and (6) of Table 12 display the results for GI. A 1% increase in CR led to a 0.656% rise in GI among labor-intensive corporations ($p < 0.01$), and a 0.825% rise among technology-intensive corporations ($p < 0.01$), both

Table 12 Heterogeneity test based on corporate factor intensity

	Labor-intensive		Technology-intensive		Capital-intensive	
	(1)	(2)	(3)	(4)	(5)	(6)
	CER	GI	CER	GI	CER	GI
CR	0.022* (0.013)	0.656*** (0.179)	0.010 (0.013)	0.825*** (0.186)	0.019 (0.012)	0.274** (0.127)
Constant	7.961*** (0.032)	0.038 (0.241)	8.009*** (0.029)	-1.887*** (0.604)	7.996*** (0.055)	-1.234** (0.588)
Industry FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Cluster	Firm	Firm	Firm	Firm	Firm	Firm
Adj. R ²	0.478	0.489	0.311	0.895	0.345	0.791

exceeding the global marginal effect of CR on GI (0.538). CR also significantly promoted GI among capital-intensive corporations ($p=0.032$), while the effect was approximately half of the global marginal effect of CR on GI (0.274 vs. 0.538).

5 Discussion

5.1 Results comparison

Comparing the findings of this study with those of existing research further demonstrates the validity and reliability of the analyzed data.

Benchmark regression results indicate that corporate CR significantly enhanced both CER and GI. This aligns with the conclusions of Z. Wang et al. (2024b) and Zhao and Liao (2025), who collectively demonstrated that corporate CR can improve carbon performance and innovation capabilities through investor supervision, market governance, and government intervention. Unexpectedly, this study found that CR did not significantly influence corporate EP, which contradicts the findings of Albitar et al. (2023) and Wang et al. (2025). One possible explanation is that prior studies often used a binary coding approach (0–1) to quantify EP, assessing whether firms disclosed specific practices such as establishing EP targets, adopting environmental management systems, or providing environmental training. However, this simplified method may capture symbolic rather than substantive environmental actions, thereby overstating the effectiveness of EP initiatives. Furthermore, growing evidence has suggested that under the influence of policy uncertainty and financial constraints, firms may resort to greenwashing strategies to gain stakeholder trust and policy support at minimal cost (Wu 2024; Abdullah et al. 2025).

To examine the greenwashing hypothesis regarding corporate EP, this study constructed a corporate environmental protection disclosure (EPD) index and empirically analyzed the relationship between EPD and EP. The specific steps were as follows. First, drawing on prior studies on environmental disclosure (Shao et al. 2024; Li 2018; Wang and Wang 2025), existing corporate EP domain keyword dictionaries were integrated and deduplicated, yielding 104 EP-related keywords. Second, the frequency of these keywords appearing in corporate annual reports was calculated, and the ratio of total keyword frequency to report length, multiplied by 100, was used to construct the corporate EPD index. Finally, using EPD as the independent variable and EP as the dependent variable, Eq. (9) was constructed to test the relationship between EPD and EP.

$$EP_{i,j,t} = \beta_0 + \beta_1 EPD_{i,j,t} + \beta_2 Controls_{i,j,t} + \psi_j + \delta_t + \varepsilon_{i,j,t} \quad (9)$$

Table 13 reports the regression results of EPD on EP. The findings reveal that although the coefficients of EPD on EP were positive, the effects were statistically insignificant, regardless of whether control variables were included ($p=0.406$ and $p=0.397$, respectively). This indicates that a higher level of EPD does not necessarily correspond to a substantive improvement in EP. In other words, the results provide empirical support for the greenwashing hypothesis, indicating that corporations may strategically engage in EPD primarily

Table 13 Regression results of EPD on EP

	(1)	(2)
	EP	EP
EPD	0.004 (0.005)	0.004 (0.005)
Constant	6.676*** (0.005)	6.641*** (0.023)
Controls	No	YES
Industry FE	YES	YES
Year FE	YES	YES
Cluster	Firm	Firm
Adj. R 2	0.256	0.266

to enhance legitimacy or satisfy stakeholder expectations, rather than to achieve genuine environmental outcomes.

Mechanism analysis results reveal that, although the proportion of female executives positively moderated the relationship between corporate CR and CRA, this effect was not statistically significant. This finding contradicts the conclusion of Zharfpeykan and Bai (2025) and may be explained by the phenomenon of “symbolic tokenism”, wherein female executives are appointed primarily to satisfy institutional requirements but are often marginalized in strategic decision-making (Nakajima et al. 2025). For instance, Ahern and Dittmar (2012) found that although the proportion of female executives increased from 9% to 40%, their influence in boardroom decisions remained limited, particularly in traditional high-carbon industries.

In addition, this study found that the proportion of executives with overseas experience and those with financial expertise significantly enhanced the effect of CR on GI, consistent with the findings of Shen et al. (2022) and Huang et al. (2019), respectively. The former study reported that, in Chinese A-share listed companies, a 1% increase in the proportion of returnee executives corresponded to a 0.225% rise in corporate GI. The later research demonstrated that financially trained executives are better at identifying policy dividends and market opportunities, often treating GI as part of a diversified portfolio.

Furthermore, mechanism analysis results indicate that media attention exerted a significant positive moderating effect on the relationship between corporate CR and CRA, including both CER and GI, consistent with the conclusions of Liang et al. (2024). However, the MLE did not significantly moderate the impact of corporate CR on CER or GI. This may be attributed to the underdevelopment of China’s carbon trading market and excessive government intervention in corporate GI. Prior studies have shown that China’s carbon trading market suffers from limited market activity, weak liquidity, and inadequate regulatory oversight, all of which hinder improvements in corporate carbon performance (Lin and Huang 2022). In addition, Peng and Kong (2024) found that when government intervention becomes overly dominant, companies tend to rely on policy support and subsidies rather than actively pursuing GI.

Heterogeneity analysis results indicate that the effect of CR on CER was more pronounced in SOEs, whereas the effect of CR on GI was stronger in POEs. Previous studies have demonstrated that, as entities operating under direct government oversight, SOEs are more responsive to regulatory directives and social expectations related to CER (Liu et al. 2025). In addition, as extensions of the government, SOEs have privileged access to policy information, subsidies, and tax incentives, enabling them to better anticipate and adapt to

carbon reduction policies amid climate policy uncertainty, thereby enhancing their carbon performance (Cull et al. 2015; Wu 2017). Conversely, Liu et al. (2020) noted that POEs, facing stronger market competition and fewer resource advantages, tend to rely on innovative activities to maintain legitimacy and competitiveness, which may explain the stronger effect of CR on GI in this group.

Furthermore, heterogeneity analysis results reveal that the effect of CR on CER was significant in labor-intensive corporations but not significant in capital- or technology-intensive corporations. This discrepancy may stem from financial constraints and the efficiency of converting research outcomes. Existing studies suggest that, under the pressure of CR, financial institutions have raised corporate credit thresholds and tightened credit availability, further constraining the CER of capital-intensive corporations (S. Zhao et al. 2025). Meanwhile, technology-intensive corporations tend to rely on scientific and technological progress to indirectly enhance their carbon performance. However, a significant threshold effect exists between technological advancement and carbon performance (L. Wang et al. 2024). The promotional effect of CR on GI across corporations with different factor intensities was statistically significant, following the order: technology-intensive > labor-intensive > capital-intensive. These findings further indicate that technology-intensive corporations, owing to their superior absorptive capacity, innovation potential, and emphasis on technological upgrading, are more inclined to adopt GI initiatives to achieve climate governance objectives while simultaneously enhancing their core competitiveness (J. Lu et al. 2025).

5.2 Theoretical implications

By examining the relationship between corporate CR and CRA, this study contributes to the knowledge system on corporate CR management.

First, this study advances the conceptualization and measurement of corporate CR and CRA. It broadens CR from physical to market and regulatory risks, framing it as a multidimensional concept encompassing both explicit and implicit climate threats. CRA is redefined as performance-based rather than declarative, with the CER, EP, and GI indices capturing firms' substantive actions. This multidimensional framework mitigates disclosure bias and enables a more rigorous analysis of the CR–CRA relationship. Second, the study extends the application of classical corporate theories, such as growth option theory, Porter's hypothesis, stakeholder theory, and environmental uncertainty theory, to the context of CR management. By empirically testing their relevance, it broadens these theories' explanatory scope and offers new perspectives on firms' strategic adaptation to environmental risks. Finally, drawing on upper echelons, institutional, and reputation theories, the study identifies how executive traits, institutional environments, and media attention moderate the CR–CRA linkage. These contextual analyses clarify the boundary conditions under which CR translates into CRA, enriching the theoretical understanding of corporate adaptation across managerial and institutional contexts.

5.3 Practical implications

This study provides several practical implications for firms, investors, regulators, and other stakeholders.

First, the results indicate that corporate CR enhances CRA, especially in CER and GI. Firms should develop systematic CR management frameworks integrating risk identification, responsive measures, and performance evaluation into their strategic and managerial systems to strengthen resilience and competitiveness. Investors are encouraged to integrate CR factors into investment decisions to identify firms with stronger adaptive capacity and innovation potential under climate change, thereby improving portfolio efficiency and risk-adjusted returns. Second, the evidence of greenwashing in EP underscores the need for regulators to refine performance-based monitoring and third-party verification mechanisms, promoting a shift from symbolic disclosure to substantive environmental action. Finally, the positive moderating role of media attention suggests that external oversight and public scrutiny are critical in advancing corporate climate governance. Regulators, the public, and the media should jointly establish transparent information and accountability systems that encourage responsible corporate behavior.

6 Conclusion and policy recommendations

Corporations are facing intensifying CR and are required to implement effective CRA. Using data from Chinese A-share listed companies from 2007 to 2022, this study employed econometric models to examine the relationship between corporate CR and CRA.

This study yields several key conclusions. The construction of the CR index reveals that Chinese corporations were experiencing increasing levels of CR, particularly firms in high-emission industries and those located in western China. The CRA index results indicate a heterogeneous upward trend in corporate CRA among Chinese firms. Among these, GI exhibited a sustained and rapid increase, whereas CER and EP displayed slower growth with greater volatility. The empirical analysis demonstrates that corporate CR significantly promoted CER and GI, while its effect on EP remained statistically insignificant. The positive effect of CR on CER was more pronounced among SOEs and labor-intensive firms, whereas its impact on GI was stronger among POEs and technology-intensive firms. The mechanism analysis further reveals that executives with overseas experience and financial expertise facilitated firms' transformation from CR exposure to GI, while the proportion of female executives had no significant moderating influence on the relationship between CR and CRA, including CER and GI. Moreover, media attention significantly amplified the positive impact of CR on CER and GI, whereas the market and legal environment did not exhibit significant moderating effects on the CR–CRA relationship.

6.1 Policy recommendations

Research findings provide valuable insights for Chinese government departments and policymakers.

First, a stable, transparent, and predictable policy environment should be fostered. The government should draw on the model of the “Five-Year Plans” to introduce the *Regulations on Medium-to-Long-Term Planning for Corporate Climate Response Actions*. Following the principle of “national coordination with corporate implementation”, climate response targets should be disaggregated into firm-level “carbon budgets” and “environmental capac-

ity” quotas, allowing for temporal flexibility. Furthermore, overarching targets should be divided into phased objectives, each supported by explicit evaluation metrics and targeted policy incentives. A policy framework structured around “quantifiable goals, assessable progress, and coherent policy linkages” would strengthen transparency and predictability, enabling firms to anticipate regulatory trends and formulate stable, long-term climate investment strategies.

Second, an integrated “prevention–detection–penalty” governance framework should be established to curb corporate greenwashing. The government should issue the *Corporate Climate Response Information Disclosure Management Measures*, defining disclosure boundaries and quantitative performance indicators. Firms should be required to submit third-party verification reports, investment evidence, and other supporting documentation to ensure a transition from declarative to performance-based disclosure. A unified “Corporate Climate Credit Database” should be developed to integrate firms’ carbon emissions, pollutant discharges, ESG reports, and annual reports, enabling cross-validation and real-time monitoring. Finally, legal definitions and accountability standards for “greenwashings” should be introduced, and the tiered penalties should be implemented to enhance deterrence and ensure the credibility of corporate climate disclosures.

Third, the government should adjust the flexibility of market incentives and legal supervision to align with the characteristics of different types of corporate CRA. Given the insufficient incentives for CER, the government should expand carbon market tools, improve the carbon market mechanism, and stimulate firms’ intrinsic motivation for CER. Furthermore, the government should enhance the regulatory framework for CER by implementing the “double random, one open” supervision model, reinforcing corporate CER assessment mechanisms, and integrating the results into corporate credit ratings. Given the market-driven nature of GI, the government should leverage market forces to guide technological innovation, factor pricing, and resource allocation. Moreover, government intervention should be continuously optimized based on the characteristics of different GI development stages to prevent excessive regulation from inhibiting corporate innovation.

6.2 Limitations and future directions

Acknowledging the study’s limitations is essential for advancing future research in this field. First, although this study constructs a corporate CR domain dictionary based on multi-source texts, it remains limited in terms of risk-type coverage, semantic recognition, and sentiment differentiation. Future research could integrate interview data and sentiment analysis to refine the lexicon and develop an emotion-tagged CR index that better captures firms’ CR. Second, while the performance-based indicators employed in this study effectively reflect firms’ substantive CRA, they may overlook “soft” dimensions such as internal governance, strategic orientation, and organizational culture. Future studies could combine performance-based and qualitative indicators to build a more comprehensive CRA framework. Finally, this study is conducted within the Chinese institutional context, where specific policy and market conditions may shape the findings. Future research could extend the analysis to other countries or regions to compare firms’ climate responses across institutional environments, thereby enhancing the external validity and generalizability of the conclusions.

Appendix

Table 14 List of abbreviations

Two-stage least squares	2SLS
Carbon Disclosure Project	CDP
Carbon emission reduction	CER
Climate risk	CR
Climate response actions	CRA
Environmental protection	EP
Environmental protection disclosure	EPD
The proportion of female executives	Female
The proportion of executives with financial expertise	Fin
Green innovation	GI
The logarithm of one plus the total number of green innovation patent applications	Green-Inv
Instrumental variable	IV
Media attention	Media
Marketization index-Intermediary Organization Development and Legal System Environment index	MLE
Negative climate risk	NegCR
The logarithm of operating income per unit of energy consumption	OIper-EC
Operating income per unit of environmental protection investment	OIper-EPI
The proportion of executives with overseas education	Oversea
Privately-owned corporations	POEs
Sustainable Development Goals	SDGs
State-owned corporations	SOEs
Variance Inflation Factors	VIF

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References

- Abdullah M, Ullah GMW, Turner J (2025) 50 shades of dark green: the nexus of narcissistic leadership and corporate greenwashing. *Int Rev Financ Anal* 104(August):104220. <https://doi.org/10.1016/j.irfa.2025.104220>

- Ahern KR, Dittmar AK (2012) The changing of the boards: the impact on firm valuation of mandated female board representation. *Q J Econ* 127(1):137–197. <https://doi.org/10.1093/qje/qjr049>
- Albitar K, Al-Shaer H, Liu YS (2023) Corporate commitment to climate change: the effect of eco-innovation and climate governance. *Res Policy* 52(2):104697. <https://doi.org/10.1016/j.respol.2022.104697>
- Arian A, Naeem MA (2025) Climate risk and corporate investment behavior in emerging economies. *Emerg Mark Rev* 65(March):101257. <https://doi.org/10.1016/j.ememar.2025.101257>
- Berk JB, Green RC, Naik V (1999) Optimal investment, growth options, and security returns. *J Finance* 54(5):1553–607. <https://doi.org/10.1111/0022-1082.00161>
- Bingler JA, Kraus M, Leippold M, Webersinke N (2024) How cheap talk in climate disclosures relates to climate initiatives, corporate emissions, and reputation risk. *J Bank Finance* 164(July):107191. <https://doi.org/10.1016/j.jbankfin.2024.107191>
- Cull R, Li W, Sun B, Xu LC (2015) Government connections and financial constraints: evidence from a large representative sample of Chinese firms. *J Corp Financ* 32(June):271–94. <https://doi.org/10.1016/j.jcorpfin.2014.10.012>
- Deng C, Su Z, Feng Y (2024) Extreme climate and corporate financialization: evidence from China. *Econ Anal Policy* 81(March):306–21. <https://doi.org/10.1016/j.eap.2023.12.001>
- DiMaggio PJ, Powell WW (1983) The iron cage revisited: institutional isomorphism and collective rationality in organizational fields. *Am Sociol Rev* 48(2):147. <https://doi.org/10.2307/2095101>
- Du J, Xu X, Yang Y (2023) Does corporate climate risk affect the cost of equity?-evidence from textual analysis with machine learning. *Chin Rev Financ Stud* 15(3):19–46+125
- Dyck A, Volchkova N, Zingales L (2008) The corporate governance role of the media: evidence from Russia. *J Finance* 63(3):1093–135. <https://doi.org/10.1111/j.1540-6261.2008.01353.x>
- Elijido-Ten EO (2017) Does recognition of climate change related risks and opportunities determine sustainability performance? *J Clean Prod* 141(January):956–966. <https://doi.org/10.1016/j.jclepro.2016.09.136>
- Elkington J (1994) Towards the sustainable corporation: win-win-win business strategies for sustainable development. *Calif Manag Rev* 36(2):90–100. <https://doi.org/10.2307/41165746>
- Elsayih J, Datt R, Hamid A (2021) CEO characteristics: do they matter for carbon performance? An empirical investigation of Australian firms. *Soc Responsib J* 17(8):1279–98. <https://doi.org/10.1108/SRJ-04-2020-0130>
- Fang X (2024) Can climate risk exposure compel companies to undergo a green transformation? *J Clean Prod* 434:140310. <https://doi.org/10.1016/j.jclepro.2023.140310>
- Freeman RE, Wicks AC, Parmar B (2004) Stakeholder theory and ‘the corporate objective revisited.’ *Organ Sci* 15(3):364–69. <https://doi.org/10.1287/orsc.1040.0066>
- Galletta S, Mazzù S, Naciti V, Vermiglio C (2022) Gender diversity and sustainability performance in the banking industry. *Corp Soc Responsib Environ Manage* 29(1):161–74. <https://doi.org/10.1002/csr.2191>
- Guo J, Yong z (2023) Climate policy uncertainty and corporate green innovation-measurement based on the text analysis method of news media. *Finance and Economy* 9:75–86. <https://doi.org/10.19622/j.cnki.cn36-1005/f.2023.09.007>
- Guo W, Huang Z, and Jie He (2023) Confucian culture and corporate climate change risk disclosure: based on text analysis and machine learning. *China J Econ* 1–35. <https://doi.org/10.16513/j.cnki.cje.20230329.001>
- Guo X, Li R (2025) Climate physical risks and corporate supply chain resilience: how do investor sentiment and risk-taking behaviors influence supply chain operations? *Financ Res Lett* 85(November):107903. <https://doi.org/10.1016/j.frl.2025.107903>
- Hambrick DC (2007) Upper echelons theory: an update. *Acad Manage Rev* 32(2):334–343. <https://doi.org/10.5465/amr.2007.24345254>
- Hamim MT, Mollah S (2025) Corporate climate risk governance and environmental innovation. *Bus Strat Environ* 34(6):7112–38. <https://doi.org/10.1002/bse.4352>
- Harjoto MA, Laksmana I, Yang Y-w (2018) Board diversity and corporate investment oversight. *J Bus Res* 90(September):40–47. <https://doi.org/10.1016/j.jbusres.2018.04.033>
- He J, Xue H, Yang W, Zhong Y, Fan B (2025) Green credit policy and corporate green innovation. *International Review of Economics & Finance* 99(April):104031. <https://doi.org/10.1016/j.iref.2025.104031>
- Hoffmann VH, Busch T (2008) Corporate carbon performance indicators: carbon intensity, dependency, exposure, and risk. *J Ind Ecol* 12(4):505–20. <https://doi.org/10.1111/j.1530-9290.2008.00066.x>
- Huang C, Nian R, Jiang Q, Zheng H (2019) Do scholar-turned businessmen spur corporate innovation? *J Financ Econ* 45(05):111–24. <https://doi.org/10.16538/j.cnki.jfe.2019.05.009>
- Hua Z, Chen G (2025) Urban financial institution density and corporate innovation information disclosure. *Financ Res Lett* 86(December):108641. <https://doi.org/10.1016/j.frl.2025.108641>
- Jia H, Huang X, Gong Y, Liu Y, Jiang H (2025) Can climate risk disclosure improve corporate green innovation? *Financ Res Lett* 83(October):107573. <https://doi.org/10.1016/j.frl.2025.107573>

- Jiang C, Li Y, Zhang X, Zhao Y (2025) Climate risk and corporate debt decision. *J Int Money Finance* 151(Febuary):103261. <https://doi.org/10.1016/j.jimonfin.2024.103261>
- Jiang X, Wang H, Xia Y (2020) Economic structural change, renewable energy development, and carbon dioxide emissions in China. *Mitig Adapt Strateg Glob Change* 25(7):1345–1362. <https://doi.org/10.1007/s11027-020-09921-6>
- Jiao A, Sun R, Ren H (2025) Navigating climate policy: corporate lobbying strategies in response to intensified climate risk exposure. *Energy Econ* 148(August):108667. <https://doi.org/10.1016/j.eneco.2025.108667>
- Jin W, Wang Y (2025) If money talks: climate change-related regulation and firms' cost of debt. *Borsa Istanbul Rev* 25(2):275–85. <https://doi.org/10.1016/j.bir.2025.01.002>
- Kang JE, Yoon DK, Rhee J (2017) Factors contributing to business actions in response to climate change in Korea. *J Risk Res* 20(3):385–403. <https://doi.org/10.1080/13669877.2015.1057203>
- Kaplan R, Levy DL (2025) The rise of investor-driven climate governance: from myth to institution? *Regul Gov* 19(2):496–510. <https://doi.org/10.1111/rego.70000>
- Khanra S, Kaur P, Joseph RP, Malik A, Dhir A (2022) A resource-based view of green innovation as a strategic firm resource: present status and future directions. *Bus Strat Environ* 31(4):1395–413. <https://doi.org/10.1002/bse.2961>
- Kouloukoui D, De Oliveira Marinho MM, Da Silva Gomes SM, De Jong P, Kiperstok A, Andrade Torres E (2020) The impact of the board of directors on business climate change management: case of Brazilian companies. *Mitig Adapt Strateg Glob Change* 25(1):127–47. <https://doi.org/10.1007/s11027-019-09864-7>
- Kouloukoui D, De Oliveira Marinho MM, Da Silva Gomes SM, Kiperstok A, Andrade Torres E (2019) Corporate climate risk management and the implementation of climate projects by the world's largest emitters. *J Clean Prod* 238(November):117935. <https://doi.org/10.1016/j.jclepro.2019.117935>
- Liang Y, Tan Q, Pang J (2024) Bless or curse, how does extreme temperature shape heavy pollution companies' ESG performance?—evidence from China. *Energy Econ* February:107378. <https://doi.org/10.1016/j.eneco.2024.107378>
- Li D, Huang M, Ren S, Chen X, Ning L (2018) Environmental legitimacy, green innovation, and corporate carbon disclosure: evidence from CDP China 100. *J Bus Ethics* 150(4):1089–104. <https://doi.org/10.1007/s10551-016-3187-6>
- Li D, Lin A, Zhang L (2019) Relationship between chief executive officer characteristics and corporate environmental information disclosure in Thailand. *Front Eng Manag* 6(4):564–74. <https://doi.org/10.1007/s42524-019-0067-7>
- Li H, Lu M (2025) Implementation of the new environmental protection law, patient capital, and corporate sustainable development. *Financ Res Lett* 86(December):108365. <https://doi.org/10.1016/j.frl.2025.108365>
- Li J, Lian G, Xu A (2023) How do ESG affect the spillover of green innovation among peer firms? Mechanism discussion and performance study. *J Bus Res* 158(March):113648. <https://doi.org/10.1016/j.jbusres.2023.113648>
- Lin B, Huang C (2022) Analysis of emission reduction effects of carbon trading: market mechanism or government intervention? *Sustain Prod Consum* 33:28–37. <https://doi.org/10.1016/j.spc.2022.06.016>
- Liu C, Zhou Z, Liu Q, Xie R, Zeng X (2020a) Can a low-carbon development path achieve win-win development: evidence from China's low-carbon pilot policy. *Mitig Adapt Strateg Glob Change* 25(7):1199–219. <https://doi.org/10.1007/s11027-019-09897-y>
- Liu J-Y, Lei Q, Li R, Zhang Y-J (2024) Resistance or motivation? Impact of climate risk on corporate greenwashing: an empirical study of Chinese enterprises. *Glob Finance J* 62:101030. <https://doi.org/10.1016/j.gfj.2024.101030>
- Liu Y, Dong K, Nepal R, Afi H (2025) How do climate risks affect corporate ESG performance? Micro evidence from China. *Res Int Bus Finance* 76:102855. <https://doi.org/10.1016/j.ribaf.2025.102855>
- Liu Z, Li X, Peng X, Lee S (2020b) Green or nongreen innovation? Different strategic preferences among subsidized enterprises with different ownership types. *J Clean Prod* 245:118786. <https://doi.org/10.1016/j.jclepro.2019.118786>
- Li W, Li N (2023) Green innovation, digital transformation and energy-intensive enterprises carbon emission reduction performance. *J Industrial Eng Eng Manage* 37(6):66–76. <https://doi.org/10.13587/j.cnki.jieem.2023.06.007>
- Li Z (2018) Will cheap talk on environmental responsibility get punished? *J World Econ* 41(12):167–188. <https://doi.org/10.19985/j.cnki.cassjwe.2018.12.009>
- Lohmann L (2011) The endless algebra of climate markets. *Capitalism Nat Socialism* 22(4):93–116. <https://doi.org/10.1080/10455752.2011.617507>
- Lu J, Li Z, Chen X-L, Yu X, Song M (2025) The influence of China's low-carbon city pilot policy on the green innovation of enterprises in the context of carbon neutrality. *J Innov Knowl* 10(6):100814. <https://doi.org/10.1016/j.jik.2025.100814>

- Lu Z, Zhang Y, Zhang Z (2025) Investors demand carbon damage risk compensation in China. *iScience* 28(10):113534. <https://doi.org/10.1016/j.isci.2025.113534>
- Lyu H, Ma C, Arash F (2024) Central environmental protection inspection, green technology innovation and carbon intensity of industrial enterprises – empirical research based on multi-period differences-in-differences model. *Energy* 307(October):132649. <https://doi.org/10.1016/j.energy.2024.132649>
- Ma L, Ma S, Tang Q et al (2024) Environmental regulation effect on the different technology innovation-based the empirical analysis. *PLoS One* 19(1):e0296008. <https://doi.org/10.1371/journal.pone.0296008>
- Marquis C, Tilsik A (2013) Imprinting: toward a multilevel theory. *Acad Manage Ann* 7(1):195–245. <https://doi.org/10.5465/19416520.2013.766076>
- McGuinness PB, Vieito JP, Wang M (2017) The role of board gender and foreign ownership in the CSR performance of Chinese listed firms. *J Corp Financ* 42(February):75–99. <https://doi.org/10.1016/j.jcorpfin.2016.11.001>
- Merkel-Davies, Doris M, Niamh MB (2007) *Discretionary Disclosure Strategies in Corporate Narratives: Incremental Information or Impression Management?*
- Milliken FJ (1987) Three types of perceived uncertainty about the environment: state, effect, and response uncertainty. *Acad Manage Rev* 12(1):133. <https://doi.org/10.2307/257999>
- Mirza SS, Yi FZ, Scrimgeour F, Corbet S (2025) Green finance and technological innovation: enhancing carbon emission control in China. *Mitig Adapt Strateg Glob Change* 30(6):45. <https://doi.org/10.1007/s11027-025-10241-w>
- Mohd Hasan Wong F, Wong DAK, Al Kez DFDR, Furszyfer Del Rio AF, Foley DR, Rooney MA, Abai 2024 (2024) Decarbonizing and offsetting emissions in the airline industry: current perspectives and strategies. *Energy* 313(December):133809. <https://doi.org/10.1016/j.energy.2024.133809>
- Mora C, McKenzie T, Gaw IM et al (2022) Over half of known human pathogenic diseases can be aggravated by climate change. *Nat Clim Chang* 12(9):869–75. <https://doi.org/10.1038/s41558-022-01426-1>
- Muchenje LT (2025) Stock liquidity and corporate climate performance: evidence from China. *J Financ Stab* 77:101389. <https://doi.org/10.1016/j.jfs.2025.101389>
- Nakajima K, Shirasu Y, Kodera E (2025) Tokenism in gender diversity on board of directors. *J Japanese Int Econ* 75(March):101342. <https://doi.org/10.1016/j.jjie.2024.101342>
- Niu S, Zhang J, Luo R, Feng Y (2023) How does climate policy uncertainty affect green technology innovation at the corporate level? New evidence from China. *Environ Res* 237(November):117003. <https://doi.org/10.1016/j.envres.2023.117003>
- Orens R, Reheul A-M (2013) Do CEO demographics explain cash holdings in SMEs? *Eur Manag J* 31(6):549–63. <https://doi.org/10.1016/j.emj.2013.01.003>
- Pan X, Pan X, Wu X, Jiang L, Guo S, Feng X (2021) Research on the heterogeneous impact of carbon emission reduction policy on R&D investment intensity: from the perspective of enterprise's ownership structure. *J Clean Prod* 328(December):129532. <https://doi.org/10.1016/j.jclepro.2021.129532>
- Peng D, Kong Q (2024) Corporate green innovation under environmental regulation: the role of ESG ratings and greenwashing. *Energy Econ* 140(December):107971. <https://doi.org/10.1016/j.eneco.2024.107971>
- Porter ME (1991) Towards a dynamic theory of strategy. *Strateg Manag J* 12(S2):95–117. <https://doi.org/10.1002/smj.4250121008>
- Qian X, Qiu S, Yang X (2024) Extreme weather exposure and corporate carbon emissions management: evidence from forty countries. *J Multinat Financ Manag* 75(September):100872. <https://doi.org/10.1016/j.mulfm.2024.100872>
- Ren Y-S, Klein T, Jiang Y (2025) Corporate investment decisions amid climate risks: relocate or stay? *J Int Money Finance* 157(August):103388. <https://doi.org/10.1016/j.jimonfin.2025.103388>
- Rogelj J, Elzen MD, Höhne N et al (2016) Paris agreement climate proposals need a boost to keep warming well below 2 °C. *Nature* 534(7609):631–639. <https://doi.org/10.1038/nature18307>
- Sakhel A (2017) Corporate climate risk management: are European companies prepared? *J Clean Prod* 165(November):103–118. <https://doi.org/10.1016/j.jclepro.2017.07.056>
- Sautner Z, Van Lent L, Vilkov G, and Ruishen Zhang (2023a) Firm-Level climate change exposure. *J Finance* 78(3):1449–1498. <https://doi.org/10.1111/jofi.13219>
- Sautner Z, Van Lent L, Vilkov G, and Ruishen Zhang (2023b) Pricing climate change exposure. *Manage Sci* 69(12):7540–7561. <https://doi.org/10.1287/mnsc.2023.4686>
- Shao S, Ge L, Zhu J (2024) How to achieve the harmony between humanity and nature: environmental regulation and environmental welfare performance from the perspective of geographical factors. *J Manage World* 40(04):119–146. <https://doi.org/10.19744/j.cnki.11-1235/f.2024.0088>
- Shen F, Qizhi Tao, and, Zhang Y (2022) Directors with overseas background and firm green technology innovation: from the perspective of corporate reputation. *J Shanghai Univ Finance Econ* 24(03):108–122. <https://doi.org/10.16538/j.cnki.jsufe.2022.03.008>

- Solangi Y, Ahmed, and Cosimo Magazzino (2025) Evaluating financial implications of renewable energy for climate action and sustainable development goals. *Renew Sustain Energy Rev* 212:115390. <https://doi.org/10.1016/j.rser.2025.115390>
- Solangi Y, Ahmed R, Alyamani, and Cosimo Magazzino (2024) Assessing the drivers and solutions of green innovation influencing the adoption of renewable energy technologies. *Heliyon* 10(9):e30158. <https://doi.org/10.1016/j.heliyon.2024.e30158>
- Tavakolifar M, Omar A, Lemma TT, Samkin G (2021aa) Media attention and its impact on corporate commitment to climate change action. *J Clean Prod* 313(September):127833. <https://doi.org/10.1016/j.jclepro.2021a.127833>
- Tavakolifar M, Omar A, Lemma TT, Samkin G (2021bb) Media attention and its impact on corporate commitment to climate change action. *J Clean Prod* 313(September):127833. <https://doi.org/10.1016/j.jclepro.2021b.127833>
- Tian L, Wu H, Zhu X (2025) Does climate risk perception drive the realization of corporate environmental responsibility? *J Behav Exp Finance* 47(September):101093. <https://doi.org/10.1016/j.jbef.2025.101093>
- Tian Y, Chen S, Dai L (2024) How climate risk drives corporate green innovation: evidence from China. *Finance Res Lett* 59(January):104762. <https://doi.org/10.1016/j.frl.2023.104762>
- Toft KH, Rüdiger M (2020) Mapping corporate climate change ethics: responses among three Danish energy firms. *Energy Res Soc Sci* 59(January):101286. <https://doi.org/10.1016/j.erss.2019.101286>
- Toukabri M, Kalai L (2024) How does sustainability leadership improve climate change reporting? The choices associated with a sustainable board- a management perspective. *Mitig Adapt Strateg Glob Change* 29(7):65. <https://doi.org/10.1007/s11027-024-10153-1>
- Wang C, Wang H, Bai Y, Shan J, Nie P, Chen Y (2024) The impact of climate policy uncertainty on corporate pollution emissions—evidence from China. *J Environ Manage* 363(July):121426. <https://doi.org/10.1016/j.jenvman.2024.121426>
- Wang J, Zhuang J, Yan C, Chan KC (2025) Standing up or standing by: abnormally hot temperatures and corporate environmental engagement. *J Bus Ethics* 196(1):93–127. <https://doi.org/10.1007/s10551-024-05682-3>
- Wang L, Chen Q, Dong Z, Cheng L (2024d) The role of industrial intelligence in peaking carbon emissions in China. *Technol Forecast Soc Change* 199(February):123005. <https://doi.org/10.1016/j.techfore.2023.123005>
- Wang R, Wang W (2025) Chinese Corporate Greenwashing Index. *Fin Res Lett* 85(November):107991. <https://doi.org/10.1016/j.frl.2025.107991>
- Wang S, Liu C, Zhou Z (2024) Government-enterprise green collaborative governance and urban carbon emission reduction: empirical evidence from green PPP programs. *Environ Res* 257(September):119335. <https://doi.org/10.1016/j.envres.2024.119335>
- Wang W, Jia Z (2020) A comparative study on the relationship between environmental performance and financial performance-based on the data of listed companies in papermaking, chemical industry and mining industry. *Friends of Accounting* 11:79–84
- Wang W, Sun Z, Wang W, Hua Q, Wu F (2023) The impact of environmental uncertainty on ESG performance: emotional vs. rational. *J Clean Prod* 397(April):136528. <https://doi.org/10.1016/j.jclepro.2023.136528>
- Wang Z, Fu H, Ren X, Gozgor G (2024aa) Exploring the carbon emission reduction effects of corporate climate risk disclosure: empirical evidence based on Chinese A-share listed enterprises. *Int Rev Financ Anal* 92(March):103072. <https://doi.org/10.1016/j.irfa.2024a.103072>
- Wang Z, Fu H, Ren X, Gozgor G (2024bb) Exploring the carbon emission reduction effects of corporate climate risk disclosure: empirical evidence based on Chinese A-share listed enterprises. *Int Rev Financ Anal* 92(March):103072. <https://doi.org/10.1016/j.irfa.2024b.103072>
- Wanhai Y, Chen S, Chen J, and Yinghua Ren (2025) The impact of ‘More words than deeds’ on environmental responsibility on stock price crash risk: the mediation effect of investor sentiment. *Chin J Manage Sci* October 14:1–16. <https://doi.org/10.16381/j.cnki.issn1003-207x.2023.1361>
- Weinhofer G, Busch T (2013) Corporate strategies for managing climate risks. *Bus Strat Environ* 22(2):121–44. <https://doi.org/10.1002/bse.1744>
- Wu A (2017) The signal effect of government R&D subsidies in China: does ownership matter? *Technol Forecast Soc Change* 117(April):339–45. <https://doi.org/10.1016/j.techfore.2016.08.033>
- Wu T (2024) Green finance reform policy increases corporate hypocritical business strategies: evidence from the greenwashing behavior. *Mitig Adapt Strateg Glob Change* 29(7):63. <https://doi.org/10.1007/s11027-024-10162-0>
- Wu X, Zheng G (2021) Does media coverage supervise large shareholders’ illegal reduction? *Foreign Economics & Management* 43(11):86–103. <https://doi.org/10.16538/j.cnki.fem.20210921.203>

- Xie Y, Ying Q (2025) Unpacking the impact of public attention on green investment: insights from climate sentiment on social media. *Int Rev Financ Anal* 104(August):104325. <https://doi.org/10.1016/j.irfa.2025.104325>
- Yan K, Chen Z, Wang J, Wang P, Liang W (2023) The power from folk monitoring: leading officials' natural resources accountability audit (NRAA) and corporate ESG performance. *Financ Res Lett* 58(December):104575. <https://doi.org/10.1016/j.frl.2023.104575>
- Yin M, Sheng L, Li W (2018) Executive incentive, innovation input and corporate performance: an empirical study based on endogeneity and industry categories. *Nankai Bus Rev* 21(1):109–117
- Yin Z, Deng R, Xia J, Zhao L (2024) Climate risk and corporate ESG performance: evidence from China. *N Am J Econ Finance* 74(September):102245. <https://doi.org/10.1016/j.najef.2024.102245>
- Yu L, Zhang W, and Qian Bi (2019) The study on the backward forcing effect of environmental tax on corporate green transformation. *China Popul Resour Environ* 29(7):112–120
- Zhang R, Jiang A, and Linlin Jiang (2025) Exposure-Sensitivity-Adaptability (ESA) framework based evaluation and characteristics analysis of urban disasters vulnerability in China. *Ecol Ind* 176:113662. <https://doi.org/10.1016/j.ecolind.2025.113662>
- Zhang R, Li Q (2025) Synergies between corporate social responsibility precedence and sustainable development goals: a pathway to corporate-led change. *J Ind Ecol* 29(3):698–718. <https://doi.org/10.1111/jiec.70003>
- Zhang S, Lu L, Zhang X, Wang H (2022) Climate risk in financial system: Assessment, Pricing, and management. *Chin Rev Financial Stud* 14(1):99–120124
- Zhang X (2024) Research on Corporate Climate Risk and Stock Pricing- An Empirical Analysis Based on Corporate Annual Report Texts. Master, Southwestern University of Finance and Economics
- Zhang X, Shi C (2025) How does environmental protection tax law affect corporate investment preferences? *Finance Res Lett* 72(February):106498. <https://doi.org/10.1016/j.frl.2024.106498>
- Zhao F, Liu Y, Dou Y, Su B (2025) Climate change risks and corporate financialization: friend or foe? A theoretical and empirical analysis. *Energy Econ* 149(September):108757. <https://doi.org/10.1016/j.eneco.2025.108757>
- Zhao H, Liao W (2025) The nexus between climate risk and corporate green innovation: the moderating role of supply chain finance. *Finance Res Lett* 85(November):107995. <https://doi.org/10.1016/j.frl.2025.107995>
- Zhao L, Liu Z, Xie C, Chen X (2025) Climate policy uncertainty and corporate carbon performance: evidence from transportation enterprises. *J Environ Manage* 390(August):126346. <https://doi.org/10.1016/j.jenvman.2025.126346>
- Zhao S, Wu Q, Zhou X (2025) Impact of green credit on financing constraints of energy-consuming firms. *Finance Res Lett* 74(March):106801. <https://doi.org/10.1016/j.frl.2025.106801>
- Zharfpeykan R, Bai Y (2025) Board gender diversity and corporate environmental, social and governance performance: evidence from New Zealand listed firms. *Pac Account Rev* 37(2):243–70. <https://doi.org/10.1108/PAR-01-2024-0011>
- Zhu L, Liu J, Liu X, Liu P (2025) The impact of multiple emission reduction policies: evidence from the coexistence of carbon emission trading system and white certificate. *Econ Model* 146(May):107027. <https://doi.org/10.1016/j.econmod.2025.107027>
- Zhu Y, Wang K (2024) Policy synergy analysis on coordinating reduction of pollution and carbon emissions in China: insights from text mining and network analysis. *J Environ Manage* 372(December):123389. <https://doi.org/10.1016/j.jenvman.2024.123389>

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