sustainability

MDPI

Article

From Green Strategic Orientation to Carbon Information Disclosure: A Statistical Indirect Pathway Through Reported Green-Transformation Intensity

Ziteng Meng [1], Yuanyuan Wang [2,*] and Wenjie Wu [3]

[1] School of Management and Engineering, Capital University of Economics and Business, Beijing 100070, China
[2] Bangor College, Central South University of Forestry and Technology, Changsha 410004, China
[3] Bangor Business School, Bangor University, Bangor LL57 2DG, UK
* Correspondence: h20190192@csuft.edu.cn

Abstract

Corporate carbon information disclosure is shaped not only by external regulatory and stakeholder pressures but also by firms' internal strategic orientation and the prominence of environmental transformation in organizational reporting. Using 31,625 firm-year observations from Chinese A-share listed firms between 2016 and 2024, this study examines the association between green strategic orientation (GSO) and carbon information disclosure (CID) and evaluates reported green-transformation intensity (RGTI) as a statistical indirect pathway. GSO is measured using an author-constructed seven-item index based on firm-level environmental disclosure indicators. RGTI is constructed from database-provided annual-report frequencies of green-transformation-related terms and is assessed against contemporaneous and one-year-ahead green investment obtained from a separate CSMAR green-investment database. The empirical analysis employs firm and year fixed effects, firm-clustered standard errors, and a three-wave design using GSO at $t-2$, RGTI at $t-1$, and CID at t. The results show that GSO is positively associated with CID. A one-standard-deviation increase in GSO is associated with an approximately 4.7-percentage-point increase in the disclosure index, equivalent to about 16.5% of its sample mean. The three-wave analysis identifies a positive and statistically significant indirect association through RGTI, although its economic magnitude is modest, accounting for approximately 8.0% of the total association. The findings remain robust to alternative measures of GSO and CID, fractional-response estimation, industry-year fixed effects, controls for general reporting propensity, and one-year-ahead disclosure specifications. Industry-based estimates indicate a weaker GSO–CID association among heavy-polluting firms, although this pattern is not reproduced when pollution exposure is measured using firm-level carbon intensity. Overall, the findings link internal environmental strategy and reported organizational attention to corporate carbon transparency while indicating that most of the GSO–CID association operates through channels beyond the measured indirect pathway.

Keywords: green strategic orientation; reported green-transformation intensity; carbon information disclosure; carbon transparency; environmental strategy; pollution exposure; China

Academic Editor: Colin Michael Hall

Received: 16 July 2026
Revised: 30 July 2026
Accepted: 3 August 2026
Published: 4 August 2026

1. Introduction

The transition toward a low-carbon economy has increased the demand for reliable and decision-useful corporate carbon information. This issue is particularly salient in China.

During the second compliance cycle of China's national emissions trading market, 2257 key emitting entities were covered, representing approximately 5.1 billion tonnes of carbon dioxide equivalent annually. By the end of 2023, cumulative allowance transactions had reached 442 million tonnes, with a total transaction value of RMB 24.919 billion [1]. In 2024, the Shanghai and Shenzhen stock exchanges issued sustainability-reporting guidelines that took effect on 1 May 2024. Under the transitional arrangements, companies subject to mandatory reporting are required to publish sustainability reports for the 2025 financial year by 30 April 2026 [2,3]. These developments have increased the importance of firms' capacity to collect, manage, and disclose carbon-related information.

Carbon information disclosure enables investors, regulators, creditors, and other stakeholders to evaluate firms' exposure to climate-related risks and assess the credibility of their environmental commitments. Climate-governance arrangements may strengthen the relationship between carbon disclosure and carbon performance [4], while capital markets attach economic significance to both corporate emissions and firms' disclosure decisions [5]. Carbon information disclosure has consequently become an important component of corporate accountability and climate governance.

Carbon disclosure should nevertheless be distinguished from verified environmental performance. Carbon accounting supports both external reporting and internal activities, including production planning, procurement, investment, innovation, and environmental decision-making [6]. Effective carbon management also requires coordination among governance structures, operational practices, emissions measurement, information systems, and reporting processes [7]. More extensive disclosure may improve transparency, but it does not necessarily demonstrate lower emissions or greater carbon efficiency. Carbon information disclosure is therefore treated in this study as a reporting outcome rather than as a direct measure of environmental performance.

Prior studies have explained variation in carbon disclosure primarily through corporate governance, institutional conditions, environmental performance, and firm characteristics. Environmental committees, institutional ownership, and board independence have been associated with voluntary carbon disclosure, particularly in environmentally sensitive industries [8]. The relationship between carbon performance and voluntary disclosure also varies across institutional settings [9]. Although this literature establishes the importance of external pressure and governance arrangements, it provides a less complete explanation of why firms exposed to similar institutional conditions differ in their willingness and organizational capacity to disclose carbon information.

Green strategic orientation offers a useful perspective on these internal differences. It refers to the extent to which environmental considerations provide an overarching direction for managerial attention, organizational arrangements, and resource-allocation decisions. The construct is related to, but distinct from, environmental orientation, environmental strategy, carbon strategy, and sustainability orientation. Environmental orientation generally reflects organizational values and behavioral responsiveness toward environmental concerns [10,11], whereas green and carbon strategies refer more directly to specific competitive, operational, or emissions-management actions [12–14]. Green strategic orientation instead captures the persistent strategic priority assigned to environmental issues across multiple areas of corporate decision-making. Existing research links this orientation to substantive green innovation and the development of green organizational capabilities [15,16], but its implications for corporate carbon disclosure remain less clearly understood.

The resource-based view suggests that environmental knowledge, managerial commitment, and accumulated organizational experience may constitute valuable firm-specific resources [17]. The dynamic-capabilities perspective further emphasizes firms' ability to recognize environmental change, allocate resources, and reconfigure organizational

routines [18]. External environmental demands do not generate uniform corporate responses because they are filtered through internal structures, managerial interpretations, and organizational capabilities [19]. A stronger green strategic orientation may therefore be associated with more systematic recognition of climate-related information needs and a greater capacity to produce and communicate carbon information.

Strategic orientation alone, however, does not reveal how prominently environmental priorities are subsequently reflected in firms' organizational agendas. This study considers reported green-transformation intensity as one potential intermediate pathway. RGTI captures the prominence of green-transformation-related content in corporate annual reports, including references to green production, technological upgrading, resource conservation, and related organizational initiatives.

RGTI is not treated as a direct measure of realized transformation. A textual-frequency indicator cannot by itself establish changes in production technology, energy efficiency, or physical emissions. It instead reflects the reported salience of green transformation in the firm's organizational agenda. Sustainability-oriented firms may develop more integrated governance processes, longer decision horizons, and more structured environmental practices [20]. Greater attention to green transformation may consequently be associated with the information-processing routines and environmental resource allocation required for more extensive carbon disclosure.

This interpretation is relevant to the distinction between substantive and symbolic environmental communication. Voluntary carbon disclosure may convey information about underlying carbon performance [21], but environmental reporting can also contain symbolic or legitimacy-oriented elements [22]. Greenwashing research shows that environmental communication may present an overly favorable image when it is not supported by corresponding organizational practices [23], while firms may selectively disclose favorable information in response to scrutiny and institutional norms [24]. Examining a temporally ordered reporting-based pathway and validating RGTI against non-textual green investment provide a more measurement-consistent basis for assessing how strategic environmental priorities are linked to carbon disclosure.

The GSO–CID association may also vary with firms' environmental exposure. Environmental regulation can stimulate organizational adjustment and innovation, but the incremental relevance of internal strategy may depend on the intensity of existing external pressure [25,26]. In China, emissions-trading and green-credit policies have increased the environmental obligations faced by carbon-intensive and heavily polluting firms [27–29]. Where regulatory scrutiny and legitimacy pressure are already strong, carbon disclosure may be driven partly by compliance and institutional expectations, leaving less incremental scope for internally developed green strategic orientation to influence reporting. This substitution mechanism implies that the GSO–CID association may be weaker among firms operating in heavy-polluting industries.

Against this background, the study addresses three questions. First, is green strategic orientation associated with subsequent corporate carbon information disclosure? Second, does reported green-transformation intensity constitute a statistical indirect pathway between green strategic orientation and carbon information disclosure? Third, does the association vary with firms' pollution exposure?

The analysis uses 31,625 firm-year observations from 4845 Chinese A-share listed firms between 2016 and 2024. Firm and year fixed-effects models are used to examine within-firm variation. The indirect pathway is evaluated using a three-wave design in which green strategic orientation precedes reported green-transformation intensity and carbon information disclosure. The annual-report-based intermediate measure is also assessed against current and subsequent green investment.

The results indicate that green strategic orientation is positively associated with subsequent carbon information disclosure. Reported green-transformation intensity constitutes a statistically significant indirect pathway, although it accounts for approximately 8% of the total association. The industry-based analysis suggests that the GSO–CID association is weaker among heavy-polluting firms, but this moderating pattern is not reproduced when pollution exposure is measured using firm-level carbon intensity.

This study contributes to the literature in three respects. First, it connects firms' internal green strategic orientation with subsequent carbon information disclosure, complementing explanations centered on external institutional conditions and corporate governance. Second, it develops a measurement-consistent account of one organizational pathway linking strategy and disclosure by interpreting RGTI as a reporting-based indicator of transformation-related attention rather than as direct evidence of realized transformation. Third, it distinguishes industry-level institutional exposure from firm-level operating carbon intensity, showing that conclusions regarding environmental pressure depend partly on how exposure is measured.

The study focuses on the extent of carbon information reported by listed firms rather than verified reductions in emissions. Its observational design supports conclusions about associations and temporally ordered statistical pathways rather than definitive causal effects.

2. Literature Review and Hypothesis Development

2.1. Green Strategic Orientation and Carbon Information Disclosure

Green strategic orientation reflects the extent to which environmental considerations are embedded in a firm's strategic priorities, managerial attention, and resource-allocation decisions. It is related to, but distinct from, environmental orientation, environmental strategy, and carbon strategy. Environmental orientation generally emphasizes organizational values and behavioral responsiveness toward environmental issues [10,11], whereas environmental and carbon strategies refer more directly to specific competitive, operational, or emissions-management actions [12–14]. Green strategic orientation represents a broader and more persistent commitment that guides environmental decision-making across multiple organizational domains.

Previous studies have linked environmental orientation and green strategy to green innovation, environmental capabilities, corporate environmental image, and sustainable performance [10–16]. In particular, green strategic orientation may direct environmental investment and human capital toward substantive green innovation [15], while green core competence supports both green innovation and corporate environmental positioning [16]. These findings suggest that environmentally oriented strategic priorities influence how firms allocate resources and develop environmental capabilities.

Carbon-disclosure research, by contrast, has focused mainly on governance arrangements, institutional conditions, environmental performance, and stakeholder pressure. Climate-governance mechanisms can affect both carbon disclosure and its alignment with carbon performance [4]. Board characteristics, environmental committees, and institutional ownership are also associated with voluntary carbon disclosure [8], while the relationship between carbon performance and disclosure varies across institutional settings [9,21]. Carbon disclosure may additionally reduce information asymmetry by allowing investors to assess firms' emissions exposure and environmental responses [5,30].

Although these studies establish the importance of external pressure and governance, they do not fully explain why firms operating under similar institutional conditions disclose carbon information to different extents. The resource-based view suggests that environmental knowledge, managerial commitment, and accumulated experience can become valuable firm-specific resources [17]. Dynamic-capabilities theory further emphasizes firms' ability

to recognize environmental change and reconfigure organizational routines [18]. Because environmental demands are interpreted through firm-specific managerial priorities and capabilities [19], a stronger green strategic orientation may increase the organizational attention and resources devoted to carbon measurement, management, and reporting.

Green strategic orientation may also strengthen the incentive to communicate environmental commitments. Firms that have incorporated environmental priorities into strategic planning have greater reason to make those commitments visible to investors, regulators, and other stakeholders. More extensive carbon disclosure can communicate strategic priorities, demonstrate accountability, and distinguish environmentally oriented firms from competitors. This argument does not imply that all disclosure reflects superior carbon performance, because reporting may also respond to legitimacy and reputational incentives [21–24]. Nevertheless, strategically oriented firms should possess both a greater internal demand for carbon information and a stronger incentive to disclose it.

H1. *Green strategic orientation is positively associated with subsequent corporate carbon information disclosure.*

2.2. Green Strategic Orientation and Reported Green-Transformation Intensity

Strategic orientation establishes broad organizational priorities, but it does not necessarily reveal how prominently those priorities are subsequently reflected in corporate activities and reporting. Firms facing comparable environmental demands may respond differently because external pressure is filtered through managerial interpretation, organizational structures, and internal capabilities [19].

This study examines reported green-transformation intensity as one observable manifestation of environmental attention. RGTI captures the prominence of green-transformation-related content in corporate annual reports, including references to cleaner production, environmental upgrading, green technology, energy conservation, resource efficiency, and related organizational initiatives.

RGTI is conceptually different from realized corporate green transformation. A textual-frequency indicator cannot directly establish changes in production technology, energy efficiency, emissions, or environmental performance. It instead reflects the reported salience of transformation-related issues within the firm's organizational agenda. GSO and RGTI also represent different stages of the proposed process. GSO captures the strategic position assigned to environmental priorities, whereas RGTI captures the subsequent prominence of transformation-related themes in formal corporate reporting.

The resource-based and dynamic-capabilities perspectives suggest that strategic priorities influence how firms deploy knowledge, capital, and managerial attention [17,18]. Sustainability-oriented firms also tend to develop more integrated organizational processes and longer decision horizons [20]. Consistent with these arguments, prior studies show that environmental and green strategic orientations are associated with sustainable organizational behavior, environmental innovation, green capabilities, and environmental investment [10–16].

External policy and financial conditions can also influence firms' environmental adjustment. Environmental regulation, emissions trading, green finance, financial technology, and climate-policy uncertainty affect environmental investment and innovation by changing compliance costs, financing conditions, information availability, and expected returns [25–29,31–34]. However, firms exposed to similar external conditions do not respond uniformly. Green strategic orientation provides an internal explanation for this variation because it shapes how external signals are interpreted and whether environmental issues receive sustained organizational attention.

Because both GSO and RGTI are partly derived from corporate reporting, their association may also reflect general reporting propensity. This potential overlap does not eliminate their conceptual distinction, but it requires empirical analysis to interpret RGTI according to what the textual measure can support. Subject to this measurement boundary, stronger green strategic orientation should precede greater reported attention to green transformation.

H2. *Green strategic orientation is positively associated with subsequent reported green-transformation intensity.*

2.3. Reported Green-Transformation Intensity and Carbon Information Disclosure

Reported green-transformation intensity may be associated with carbon disclosure because both depend on the organizational importance assigned to environmental issues. Firms that devote greater attention to cleaner production, technological upgrading, resource conservation, and environmental-management initiatives are more likely to identify carbon-related matters as relevant to corporate decision-making and external accountability.

Environmental activities can also contribute to the information environment underlying carbon disclosure. Green investment, cleaner-production projects, energy-efficiency programs, and environmental-management systems generally require firms to define targets, allocate responsibilities, monitor implementation, and evaluate environmental outcomes. These processes may generate information about energy use, emissions, environmental expenditure, production technologies, and organizational responsibilities.

Carbon accounting serves both internal management and external reporting purposes [6]. An integrated carbon-management system similarly connects governance structures and operational activities with emissions tracking, reporting, and stakeholder engagement [7]. Greater reported attention to green transformation may therefore be associated with a stronger informational basis for disclosing carbon governance, risks, targets, and environmental initiatives.

The relationship is nevertheless not unambiguous. Voluntary carbon disclosure may reflect underlying carbon performance [21], but sustainability reporting can also contain symbolic or legitimacy-oriented elements [22]. Environmental communication may contribute to greenwashing when favorable claims are not supported by corresponding practices [23,24]. Standalone corporate social responsibility reports can operate either as credible signals or as impression-management instruments [35], and firms may choose between substantive environmental activities and communication-oriented responses [36].

RGTI does not eliminate this ambiguity. A higher frequency of transformation-related language may reflect organizational attention, ongoing environmental initiatives, reporting emphasis, or a combination of these factors. It does not prove that a firm has completed substantive green transformation. Nevertheless, firms in which transformation-related environmental issues are more prominent should have stronger incentives and a broader informational basis for subsequent carbon reporting.

H3. *Reported green-transformation intensity is positively associated with subsequent corporate carbon information disclosure.*

2.4. The Statistical Indirect Role of Reported Green-Transformation Intensity

The preceding arguments imply a temporally ordered relationship among green strategic orientation, reported green-transformation intensity, and carbon information disclosure. GSO establishes the strategic importance assigned to environmental objectives. This strategic emphasis may subsequently increase the prominence of transformation-related issues in the firm's organizational agenda and formal reporting. Greater RGTI may then be associated with more extensive carbon disclosure.

This sequence is consistent with the distinction between organizational resources and their deployment. Environmental knowledge, managerial commitment, and strategic attention may represent valuable intangible resources, but their relevance depends on how they are incorporated into organizational processes [17]. Dynamic-capabilities theory similarly emphasizes resource reconfiguration rather than passive resource possession [18]. RGTI represents one observable, reporting-based indication that transformation-related environmental issues have gained organizational salience.

The indirect pathway is not expected to account for the entire relationship. GSO may also be associated with carbon disclosure through board oversight, managerial awareness, stakeholder engagement, reputational incentives, carbon-accounting systems, and other organizational channels. RGTI therefore represents one possible pathway rather than a comprehensive explanation.

Because the research design is observational and the variables partly share reporting origins, the pathway is examined as statistical rather than causal mediation. Evidence that earlier GSO is associated with subsequent RGTI and that RGTI is associated with later CID would be consistent with a positive statistical indirect relationship.

H4. *Reported green-transformation intensity constitutes a positive statistical indirect pathway between green strategic orientation and subsequent corporate carbon information disclosure.*

2.5. Pollution Exposure as a Moderating Condition

The association between green strategic orientation and carbon information disclosure may vary with firms' environmental exposure. Heavy-polluting firms are generally more visible to regulators, creditors, investors, media organizations, and local communities because their operations create greater environmental externalities. Environmental regulation, emissions trading, green credit, and green-finance policies therefore have particularly important consequences for their environmental investment, innovation, and operating decisions [25–29,31,32,37].

Greater external scrutiny may increase the overall level of environmental disclosure among heavy-polluting firms. However, it may also reduce the incremental relevance of internally developed green strategic orientation. When carbon reporting is already strongly influenced by regulatory monitoring, financing requirements, and legitimacy pressure, firms may disclose environmental information partly regardless of the strength of their voluntary strategic orientation.

Non-heavy-polluting firms generally face less direct environmental scrutiny. Their carbon disclosure may consequently depend more strongly on whether managers have voluntarily embedded environmental priorities within corporate strategy. Green strategic orientation should therefore have greater marginal relevance when external disclosure pressure is comparatively weaker.

This reasoning reflects a substitution mechanism between external and internal disclosure incentives. It does not imply that heavy-polluting firms necessarily disclose less carbon information. Instead, it predicts that the slope of the GSO–CID association is weaker in industries where external regulation and legitimacy pressure already play a substantial role.

Previous studies show that climate-policy conditions, green-finance policies, and media scrutiny can affect the environmental innovation, pollution emissions, and strategic environmental activities of heavily polluting firms [34,37–39]. These findings support the view that pollution-intensive firms operate under distinctive institutional pressures. Accordingly:

H5. *The positive association between green strategic orientation and corporate carbon information disclosure is weaker among firms operating in heavy-polluting industries than among firms operating in non-heavy-polluting industries.*

Figure 1 presents the conceptual framework. Green strategic orientation is associated with carbon information disclosure directly and indirectly through reported green-transformation intensity. Heavy-polluting-industry status moderates the association between green strategic orientation and carbon information disclosure.

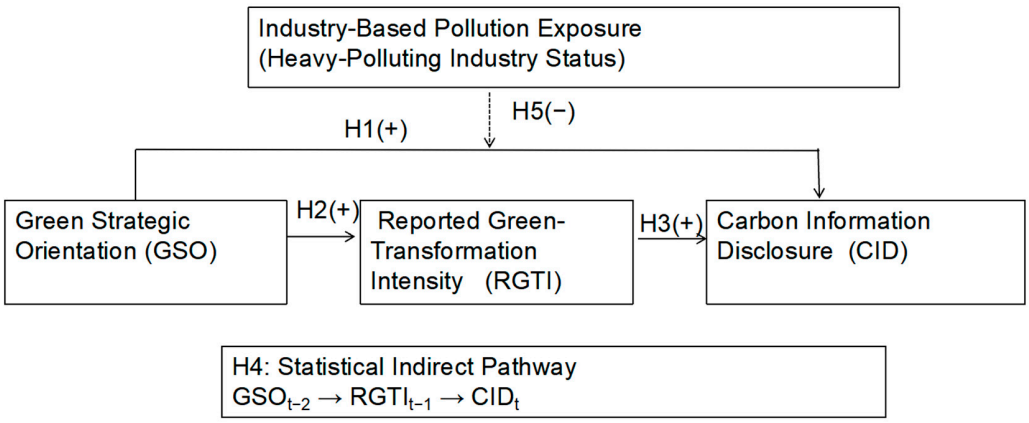

Figure 1. Conceptual framework. Note: GSO denotes green strategic orientation; RGTI denotes reported green-transformation intensity; and CID denotes carbon information disclosure. H4 represents a temporally ordered statistical indirect pathway rather than a causal mediation effect. H5 predicts that heavy-polluting industry status weakens the positive association between GSO and CID. Firm-level carbon intensity is examined as a supplementary measure of pollution exposure and is therefore not separately included in the conceptual framework.

3. Research Design

3.1. Sample Selection and Data Sources

This study examines Chinese A-share listed firms over the period 2016–2024. The sample begins in 2016 because firm-level annual-report textual data on green-transformation-related expressions are available from that year onward. Observations from 2015 are retained during data processing only to construct one-year-lagged green strategic orientation measures and are not included in the reported estimation sample. The three-wave indirect-pathway analysis begins in 2018 because it requires green strategic orientation measured at $t - 2$, reported green-transformation intensity measured at $t - 1$, and carbon information disclosure measured at t.

The principal data are obtained from the China Stock Market & Accounting Research database (CSMAR). CSMAR does not provide pre-constructed GSO1 or GSO2 indices. The green strategic orientation measures are author-constructed from seven underlying firm-level environmental disclosure items obtained from CSMAR, as described in Section 3.2.2 and Appendix A Table A3.

Reported green-transformation intensity is constructed from a separate CSMAR annual-report textual database that records firm-level frequencies of green-transformation-related words and sentences. Carbon information disclosure data, including the aggregate, soft, and hard disclosure measures, are obtained from CSMAR's corporate carbon-disclosure records.

The green-investment variables used for construct validation are obtained from the Listed Companies Green Environmental Investment Summary Table in the licensed CSMAR Listed Companies Green Investment Database. This database is separate from the Green Supply Chain Research Database used to construct RGTI. It reports firm-year monetary amounts for expensed green investment recognized in administrative and research-and-development expenses and capitalized green investment recognized in construction in progress, fixed assets, and development expenditures. Total green investment is constructed

by the authors as the sum of the identified capitalized and expensed components. The database also provides total assets and operating revenue for constructing investment-intensity measures. The supplementary firm-level carbon-intensity data are compiled from CSMAR information and listed firms' annual reports. The original dataset covers Chinese A-share listed firms from 2000 to 2023 and contains 42,191 firm-year observations. It reports total carbon emissions, operating revenue, carbon intensity, operating costs, and carbon-performance indicators. According to the dataset documentation, the construction of these measures draws on the approaches discussed by Wang et al. [40] and He et al. [41]. Because the carbon-intensity variable is a secondary compiled estimate rather than a uniformly disclosed measure of directly verified emissions, it is used only as a supplementary firm-level proxy for pollution exposure.

For the pollution-exposure analysis, carbon intensity is measured at $t-1$ and matched with carbon information disclosure at t. Carbon-intensity observations from 2015 to 2023 are therefore aligned with carbon-disclosure outcomes from 2016 to 2024. This timing permits the latest available 2023 carbon-intensity observation to be matched with the 2024 disclosure outcome.

The initial sample contains 38,381 firm-year observations for the period 2016–2024. Observations outside the Shanghai and Shenzhen A-share markets are first excluded. Financial firms are then removed because their accounting structures, leverage characteristics, and regulatory environments differ from those of non-financial firms. ST and PT firm-year observations are excluded because they may be affected by abnormal financial conditions and special trading restrictions. The remaining observations are matched with the RGTI, carbon-disclosure, financial, and governance datasets. Observations without valid one-year-lagged GSO measures or complete control variables are subsequently removed. Finally, singleton firms that do not contribute to within-firm fixed-effects estimation are excluded from the baseline estimation panel.

These procedures yield an unbalanced baseline panel of 31,625 firm-year observations representing 4845 listed firms. The three-wave indirect-pathway sample contains 20,008 observations from 3844 firms after requiring the necessary consecutive-year information and excluding singleton observations. The validation and supplementary analyses use different sample sizes because of additional data-availability and timing requirements; the applicable sample sizes are reported in the corresponding tables.The sample-selection procedure and the number of observations retained at each stage are summarized in Table 1.

To reduce the influence of extreme observations, all continuous financial and governance control variables are winsorized at the 1st and 99th percentiles. Bounded disclosure indices, binary variables, and logarithmically transformed textual measures are not additionally winsorized unless otherwise specified.

To examine whether sample attrition is associated with observable firm characteristics, Appendix A Table A1 compares the retained baseline sample with observations excluded because of unavailable lagged GSO values or missing control variables. The comparisons cover firm size, state ownership, manufacturing-industry status, heavy-polluting-industry status, carbon information disclosure, and the overall CSRC industry distribution. The results indicate that the excluded observations differ from the retained sample along several observable dimensions. Observations without valid lagged GSO values are generally smaller, less likely to be state-owned, more likely to operate in manufacturing industries, and characterized by lower carbon disclosure. Observations excluded because of missing controls are generally larger, more likely to be state-owned, less likely to operate in manufacturing industries, and characterized by slightly higher carbon disclosure. The heavy-polluting-industry difference is not statistically significant for the missing-controls group. These findings indicate that sample attrition is not random with respect to ob-

servable firm characteristics. Accordingly, the empirical results should be interpreted as applying primarily to listed firms with sufficient longitudinal information and complete control-variable data.

Table 1. Sample selection procedure.

Step	Sample-Selection Procedure	Observations Removed	Observations Remaining	Firms Remaining
1	Initial green strategic orientation observations, 2016–2024	—	38,381	5583
2	Excluding non-Shanghai/Shenzhen A-share observations	745	37,636	5318
3	Excluding financial firms	961	36,675	5212
4	Excluding ST/PT firm-year observations	1088	35,587	5201
5	Retaining observations matched with reported green-transformation data	238	35,349	5200
6	Retaining observations matched with carbon information disclosure data	107	35,242	5200
7	Retaining observations matched with financial and governance data	1	35,241	5200
8	Excluding observations without valid lagged green strategic orientation	2432	32,809	5122
9	Excluding observations with missing control variables	913	31,896	5116
10	Excluding singleton firms from the baseline estimation panel	271	31,625	4845

Notes: Observations from 2015 are retained only to construct one-year-lagged green strategic orientation measures and are not included in the reported sample. ST/PT observations are excluded on a firm-year basis. The final step removes singleton firms that do not contribute to within-firm fixed-effects estimation. Continuous financial and governance control variables are winsorized at the 1st and 99th percentiles.

3.2. Variable Measurement

3.2.1. Carbon Information Disclosure

The dependent variable is corporate carbon information disclosure. The original CSMAR carbon information disclosure score, denoted as CID, has a theoretical range from 0 to 50. A higher score indicates that a firm discloses a broader range of carbon-related information. The detailed dimensions, component indicators, and scoring rules of the carbon information disclosure index are reported in Appendix A Table A2.

The principal dependent variable is the standardized carbon information disclosure score:

$$CID\_std_{i,t} = \frac{CID_{i,t}}{50}.$$

The standardized measure ranges from zero to one and represents the proportion of the maximum carbon-disclosure score attained by a firm. This transformation facilitates coefficient interpretation while preserving the relative information contained in the original disclosure index.

For robustness analysis, the study also employs the logarithmically transformed original disclosure score:

$$LnCID_{i,t} = \ln(1 + CID_{i,t})$$

To address potential conceptual overlap between green strategic orientation and the strategy-oriented or qualitative components of the aggregate carbon-disclosure index, the study additionally uses hard carbon disclosure. The original HardCID score ranges from

0 to 28 and places greater emphasis on quantitative, outcome-oriented, and potentially verifiable carbon information. It is standardized as follows:

$$HardCID\_frac_{i,t} = \frac{HardCID_{i,t}}{28}.$$

Because both CID_std and $HardCID\_frac$ are fractional outcomes bounded between zero and one, fractional-response specifications are also estimated as robustness tests.

3.2.2. Green Strategic Orientation

Green strategic orientation is the principal explanatory variable. As CSMAR does not provide a pre-constructed green strategic orientation index, this study develops two measures based on seven firm-level environmental disclosure items obtained from CSMAR. The selection and classification of these items are informed by the literature on green strategic orientation, environmental strategy, and formal environmental-management arrangements.

The seven items indicate whether a firm discloses: (1) an environmental philosophy; (2) environmental objectives; (3) an environmental management system; (4) certification under, or implementation of, the ISO 14001 environmental management system standard [42]; (5) environmental education and training; (6) special environmental activities; and (7) implementation of the environmental "Three Simultaneities" system.

Each item is assigned a value of one when the corresponding environmental statement, system, or practice is disclosed and zero otherwise. GSO1 is calculated as the sum of all seven items and ranges from 0 to 7. A higher value indicates that environmental considerations are reflected across a broader range of the firm's reported strategic and organizational arrangements.

As an alternative measure, GSO2 is constructed from the first four items: environmental philosophy, environmental objectives, environmental management systems, and ISO 14000-related certification or implementation. It ranges from 0 to 4 and focuses more narrowly on the strategic-policy and formal institutional dimensions of green orientation. By excluding environmental training, special environmental activities, and the "Three Simultaneities" system, GSO2 provides a more concentrated measure of formal green strategic orientation rather than a simple rescaling of GSO1.

The underlying items, coding rules, and aggregation procedures are presented in Appendix A Table A3. Because both measures are constructed from disclosed environmental information, they are interpreted as proxies for reported green strategic orientation rather than as direct observations of managerial intentions.

The baseline analysis uses the one-year-lagged value of GSO1:

$$L.GSO1_{i,t} = GSO1_{i,t-1}.$$

The lagged specification establishes temporal precedence between reported green strategic orientation and subsequent carbon information disclosure and reduces, although it does not eliminate, concerns regarding simultaneity and reverse temporal ordering. The one-year-lagged value of GSO2 is used in the alternative-measure analysis.

3.2.3. Reported Green-Transformation Intensity

The proposed intermediate variable is reported green-transformation intensity (RGTI). It captures the prominence of green-transformation-related content in listed firms' annual reports. Because textual frequency cannot directly establish realized changes in production technology, energy efficiency, resource allocation, or physical emissions, RGTI is interpreted as a reporting-based indicator of the organizational salience of green transformation rather than as a direct measure of substantive corporate green transformation.

The textual data are obtained from the China Listed Companies Green Supply Chain Research Database distributed through CSMAR. This database contains two related tables. The keyword-level detail table, GSC_GreenTranWordFreqDet, records firm identifiers, reporting dates, document sources, green-transformation keywords, keyword frequencies, and the frequencies of sentences containing those keywords. The firm-year statistical table, GSC_GreenTranWordFreqStat, provides database-aggregated annual-report word frequencies, sentence frequencies, and report-length measures. The baseline analysis uses the annual-report fields rather than the corresponding social-responsibility-report fields.

The principal RGTI measure is constructed from the database-provided annual-report total word-frequency field, ARGRTtlWrdFrqncy, as follows:

$$RGTI_{i,t} = \ln(1 + GTWordFreq_{i,t}),$$

where $GTWordFreq_{i,t}$ denotes the total frequency of all green-transformation-related keywords in firm i's annual report in year t. A higher value indicates that green-transformation-related issues receive greater prominence in the firm's annual reporting. The logarithmic transformation reduces the influence of the strongly right-skewed frequency distribution while retaining firm-year observations for which the database reports zero total frequency.

Two alternative textual measures are employed. The first uses the database-provided annual-report total sentence-frequency field, ARGRTtlSntnncFrqncy:

$$RGTI\_Sentence_{i,t} = \ln(1 + GTSentenceFreq_{i,t}),$$

$GTSentenceFreq_{i,t}$ denotes the total number of annual-report sentences containing green-transformation-related keywords.

The second measure adjusts the total word frequency for annual-report length:

$$RGTI\_Density_{i,t} = \frac{GTWordFreq_{i,t}}{AnnualReportWords_{i,t}} \times 10,000.$$

where $AnnualReportWords_{i,t}$ is obtained from the CSMAR field AnnRprtTotalWordsNum. This measure represents the number of green-transformation-related keyword occurrences per 10,000 annual-report words.

Because longer annual reports may mechanically contain more green-transformation-related terms, the baseline and alternative regressions also control for annual-report length:

$$ReportLength_{i,t} = \ln(AnnualReportWords_{i,t}).$$

The database documentation does not disclose the complete proprietary keyword dictionary or the upstream procedures used to tokenize reports, identify sentences, remove non-substantive report content, or construct the database-provided aggregate frequency fields. The authors therefore do not attempt to reconstruct these underlying procedures. The post-download processing conducted in this study is limited to converting reporting dates into fiscal years, matching firms by stock code and year, applying the logarithmic transformations, and constructing the report-length-adjusted density measure. Appendix A Table A4 reports the exact CSMAR source tables, original field identifiers, database-provided definitions, and author-performed construction steps.

To assess the convergent validity of RGTI, the textual measure is matched with firm-level green-investment data obtained independently from the Listed Companies Green Environmental Investment Summary Table in the CSMAR Listed Companies Green Investment Database. These variables are not derived from the green-transformation textual database and therefore provide non-textual validation outcomes. Both contemporaneous

and one-year-ahead green-investment outcomes are examined. Detailed definitions of the green-investment measures are provided in Section 3.2.5.

3.2.4. Control Variables

The analysis controls for firm-level financial, governance, ownership, and audit characteristics that may be associated with both green strategic orientation and carbon information disclosure.

Firm size (Size) is measured as the natural logarithm of total assets. Larger firms generally face greater stakeholder scrutiny and possess more resources to collect, verify, and disclose carbon-related information.

Leverage (Lev) is measured as total liabilities divided by total assets. Highly leveraged firms may face stronger creditor monitoring, although financial pressure may also constrain environmental investment and disclosure activities.

Return on assets (ROA) captures firm profitability. Firms with better financial performance may have greater capacity to support environmental management, green investment, and carbon information disclosure.

Firm growth (Growth) is measured using the firm growth-rate indicator provided by CSMAR. Firms experiencing rapid growth may face different environmental investment needs and disclosure incentives.

Operating cash flow (Cashflow) is measured as operating cash flow divided by total assets. It captures the internal financial resources available to support environmental management and disclosure.

Fixed-asset intensity (FIXED) is measured as fixed assets divided by total assets. Firms with greater fixed-asset intensity may have higher energy consumption and greater exposure to carbon-related operational risks.

Board size (Board) is measured as the natural logarithm of the number of directors.

Board independence (Indep) is measured as the proportion of independent directors on the board.

CEO duality (Dual) equals one when the chairperson and chief executive officer positions are held by the same individual and zero otherwise.

Largest-shareholder ownership (Top1) is measured as the ownership proportion of the largest shareholder.

Firm age (FirmAge) is measured using the logarithmic firm-age indicator provided by CSMAR.

State ownership (SOE) equals one for state-owned enterprises and zero otherwise.

Big Four auditor status (Big4) equals one when the firm is audited by a Big Four accounting firm and zero otherwise.

All continuous financial and governance control variables are winsorized at the 1st and 99th percentiles. Dummy variables, including Dual, SOE, and Big4, are not winsorized.

In the baseline specification, the controls are measured in year t. In the three-wave indirect-pathway analysis, the controls and annual-report length are measured in year $t - 1$, consistent with the timing of the proposed intermediate variable.

3.2.5. Additional Variables for Validation and Robustness

Several additional variables are used to assess construct validity, reporting-related confounding, alternative disclosure content, and pollution exposure.

Firm-level green investment is used to assess the convergent validity of reported green-transformation intensity. The underlying data are obtained from the CSMAR Listed Companies Green Investment Database, specifically the Listed Companies Green Environmental

Investment Summary Table, and are independent of the annual-report textual-frequency data used to construct RGTI.

Capitalized green investment consists of environmentally related expenditures recognized in construction in progress, fixed assets, and development expenditures. Expensed green investment consists of environmentally related expenditures recognized in administrative and research-and-development expenses. Total green investment is author-constructed as the sum of the capitalized and expensed components. An additional indicator equals one when positive green investment is identified and zero otherwise.

Hard carbon information disclosure is employed as an alternative dependent variable. The original hard-disclosure score ranges from 0 to 28 and places greater emphasis on quantitative, outcome-oriented, and potentially verifiable carbon information. The fractional measure, HardCID_frac, is calculated by dividing the original score by 28.

General reporting propensity is measured using an indicator equal to one when a firm issues a separate corporate social responsibility report and zero otherwise. The length of the separate report is measured as the natural logarithm of one plus its total number of words. An alternative measure based on the natural logarithm of one plus the total number of characters is also used. These variables help distinguish carbon-specific disclosure from firms' broader propensity to produce extensive non-financial reports.

Industry-based pollution exposure is measured using the HeavyPollute indicator. The indicator equals one when a firm is classified as operating in a heavy-polluting industry and zero otherwise. The classification is based on the environmental regulatory catalog issued by the former Ministry of Environmental Protection and is matched to the relevant CSRC industry codes [42,43]. The detailed industry classification is reported in Appendix A Table A5.

The industry-based measure is supplemented with firm-level carbon intensity compiled from CSMAR information and listed firms' annual reports. According to the dataset documentation, the construction of the carbon-emission and carbon-intensity measures draws on the approaches discussed by Wang et al. [40] and He et al. [41]. The database-provided carbon-intensity variable is used rather than reconstructed from the displayed emissions and revenue fields because the underlying data may reflect differences in units, estimation procedures, and processing conventions.

Carbon intensity is measured at $t-1$ and matched with carbon information disclosure at t. To reduce the influence of extreme upper-tail observations while retaining zero and low-intensity observations, carbon intensity is capped at the annual 99th percentile. The logarithmic measure is calculated as:

$$LnCI_{i,t} = \ln(1 + CarbonIntensity_{i,t}).$$

The supplementary specifications use the annual mean-centered value of LnCI and firms' percentile ranks within the annual carbon-intensity distribution. These measures capture firm-year operating intensity and are not treated as mechanically equivalent substitutes for the industry-based regulatory classification. The definitions and measurement procedures for the variables used in the empirical analyses are summarized in Table 2.

Table 2. Variable definitions.

Variable	Definition
CID_std	Standardized carbon information disclosure score, calculated as the original CSMAR carbon disclosure score divided by its theoretical maximum of 50
LnCID	Natural logarithm of one plus the original carbon information disclosure score

Table 2. *Cont.*

Variable	Definition
HardCID_frac	Hard carbon information disclosure score divided by its theoretical maximum of 28
L.GSO1	One-year-lagged author-constructed sum of seven binary environmental disclosure items, ranging from 0 to 7; interpreted as the breadth of reported green strategic orientation
L.GSO2	One-year-lagged author-constructed sum of the four strategic-policy and formal environmental-management items included in GSO1, ranging from 0 to 4
RGTI	Natural logarithm of one plus the annual-report total green-transformation word frequency reported in the CSMAR field ARGRTtlWrdFrqncy; interpreted as reported green-transformation intensity
RGTI_Sentence	Natural logarithm of one plus the annual-report total green-transformation sentence frequency reported in the CSMAR field ARGRTtlSntnncFrqncy
RGTI_Density	Annual-report total green-transformation word frequency divided by total annual-report words (AnnRprtTotalWordsNum) and multiplied by 10,000
ReportLength	Natural logarithm of total annual-report words reported in AnnRprtTotalWordsNum
L.CSR_Report	One-year-lagged indicator equal to one when the firm issues a separate CSR-related report and zero otherwise
L.LnCSRWords	One-year-lagged natural logarithm of one plus the total number of words in the firm's separate CSR-related report
L.LnCSRChars	One-year-lagged natural logarithm of one plus the total number of characters in the firm's separate CSR-related report
GreenInvestment	Inverse hyperbolic sine of total identified green investment, author-constructed as the sum of capitalized and expensed green-investment components
CapitalizedGreenInvestment	Inverse hyperbolic sine of environmentally related amounts recognized in construction in progress, fixed assets, and development expenditures
ExpensedGreenInvestment	Inverse hyperbolic sine of environmentally related amounts recognized in administrative and research-and-development expenses
GreenInvestmentIntensity	Total identified green investment divided by total assets
GreenInvestmentDummy	Indicator equal to one when positive identified green investment is observed and zero otherwise
HeavyPollute	Indicator equal to one when the firm's primary industry is included in the heavy-polluting industry classification and zero otherwise
CarbonIntensity	Database-provided firm-level carbon-intensity measure compiled from CSMAR information and listed firms' annual reports; capped at the annual 99th percentile before transformation
LnCI	Natural logarithm of one plus the capped firm-level carbon-intensity measure
YearCenteredLnCI	Log carbon intensity minus its annual sample mean
CIPercentile	Firm's percentile rank in the annual distribution of the capped carbon-intensity measure, ranging from 0 to 1
CenteredCIPercentile	Annual carbon-intensity percentile rank minus 0.5
Size	Natural logarithm of total assets
Lev	Total liabilities divided by total assets
ROA	Net income divided by total assets
Growth	Operating-revenue growth rate
Cashflow	Net operating cash flow divided by total assets
FIXED	Fixed assets divided by total assets
Board	Natural logarithm of the number of directors

Table 2. *Cont.*

Variable	Definition
Indep	Proportion of independent directors on the board
Dual	Indicator equal to one when the chairperson also serves as chief executive officer and zero otherwise
Top1	Ownership proportion of the largest shareholder
FirmAge	Natural logarithm of firm age
SOE	Indicator equal to one for state-owned enterprises and zero otherwise
Big4	Indicator equal to one when the firm is audited by a Big Four accounting firm and zero otherwise

Notes: GSO1 and GSO2 are constructed by the authors from underlying firm-level environmental disclosure items obtained from CSMAR; CSMAR does not provide pre-constructed composite GSO indices. The RGTI measures are constructed from the database-provided annual-report fields in the GSC_GreenTranWordFreqStat table of the China Listed Companies Green Supply Chain Research Database. The green-investment variables are obtained independently from the Listed Companies Green Environmental Investment Summary Table in the CSMAR Listed Companies Green Investment Database and are not derived from the RGTI textual data. All continuous financial and governance control variables are winsorized at the 1st and 99th percentiles.

3.3. Empirical Models

3.3.1. Baseline Association Between Green Strategic Orientation and Carbon Information Disclosure

To examine the within-firm association between green strategic orientation and carbon information disclosure, the following firm and year fixed-effects model is estimated:

$$CID\_std_{i,t} = \alpha_0 + \alpha_1 GSO_{i,t-1} + \boldsymbol{\alpha}_2 Controls_{i,t} + \alpha_3 ReportLength_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t}. \quad (1)$$

In Equation (1), i and t denote firm and year, respectively. $CID\_std_{i,t}$ is the standardized carbon information disclosure score. $GSO_{i,t-1}$ represents one-year-lagged green strategic orientation. $Controls_{i,t}$ denotes the vector of firm-level financial, governance, ownership, and audit controls. $ReportLength_{i,t}$ controls for the total length of the firm's annual report.

Firm fixed effects, μ_i, absorb time-invariant firm characteristics, whereas year fixed effects, λ_t, capture macroeconomic conditions, regulatory developments, and common temporal shocks.

A positive and statistically significant α_1 is consistent with the proposed positive association between green strategic orientation and carbon information disclosure. Because the research design remains observational, α_1 is interpreted as a conditional within-firm association rather than as a definitive causal effect.

3.3.2. Three-Wave Statistical Indirect-Pathway Analysis

The proposed indirect pathway is examined using a three-wave temporal structure. Green strategic orientation is measured at t − 2, reported green-transformation intensity is measured at t − 1, and carbon information disclosure is measured at t.

The total association between green strategic orientation and subsequent carbon information disclosure is first estimated as follows:

$$CID\_std_{i,t} = \tau_0 + \tau_1 GSO_{i,t-2} + \boldsymbol{\tau}_2 Controls_{i,t-1} + \tau_3 ReportLength_{i,t-1} + \mu_i + \lambda_t + \varepsilon_{i,t}. \quad (2)$$

The association between green strategic orientation and reported green-transformation intensity is estimated using:

$$RGTI_{i,t-1} = a_0 + a_1 GSO_{i,t-2} + \boldsymbol{a}_2 Controls_{i,t-1} + a_3 ReportLength_{i,t-1} + \mu_i + \lambda_t + \varepsilon_{i,t-1}. \quad (3)$$

Finally, carbon information disclosure is regressed jointly on green strategic orientation and reported green-transformation intensity:

$$CID\_std_{i,t} = c_0 + c'GSO_{i,t-2} + bRGTI_{i,t-1} + \boldsymbol{c}_2 Controls_{i,t-1} + c_3 ReportLength_{i,t-1} + \mu_i + \lambda_t + \varepsilon_{i,t}. \quad (4)$$

The proposed indirect association is calculated using the coefficient product:

$$Indirect\ Association = a_1 \times b.$$

The direct association is represented by c', whereas the total association is represented by τ_1. The proportion of the total association statistically accounted for by the proposed pathway is calculated as:

$$Mediated\ Share = \frac{a_1 \times b}{\tau_1}.$$

The statistical significance of the coefficient product is evaluated using 5000 firm-clustered bootstrap replications. Normal-based, percentile, and bias-corrected confidence intervals are calculated, with the bias-corrected interval used as the principal basis for inference.

A statistically significant coefficient product is interpreted as evidence of a temporally ordered statistical indirect association. The analysis does not treat temporal ordering, fixed effects, and lagged variables as sufficient to establish causal mediation because unobserved time-varying factors may still jointly affect reported green-transformation intensity and carbon information disclosure.

The three-wave analysis is also re-estimated using $HardCID\_frac$ as the dependent variable. This specification evaluates whether the statistical indirect pathway remains present when the disclosure outcome focuses more heavily on quantitative and outcome-oriented carbon information.

3.3.3. Pollution Exposure as a Moderating Condition

The model includes the main effect of HeavyPollute and its interaction with lagged GSO. Although heavy-polluting-industry status is persistent for most firms, it may change when a firm's reported primary industry classification changes. Under firm fixed effects, the coefficient on HeavyPollute is therefore identified from within-firm changes in industry classification. The coefficient on the interaction term provides the formal test of whether the GSO–CID association differs between heavy-polluting and non-heavy-polluting firms.

$$\begin{aligned} CID\_std_{i,t} = \quad & \delta_0 + \delta_1 GSO_{i,t-1} + \delta_2 HeavyPollute_{i,t} \\ & + \delta_3 (GSO_{i,t-1} \times HeavyPollute_{i,t}) + \delta_4 Controls_{i,t} \\ & + \delta_5 ReportLength_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t}. \end{aligned} \quad (5)$$

In Equation (5), $HeavyPollute_{i,t}$ equals one when firm i is classified as operating in a heavy-polluting industry in year t, and zero otherwise. Although the classification is relatively persistent, it may vary for firms whose reported industry classification changes over time. The model therefore includes both the heavy-pollution indicator and its interaction with lagged GSO.

The coefficient δ_1 represents the conditional association between lagged GSO and CID among non-heavy-polluting firms, which constitute the reference group. The corresponding association among heavy-polluting firms is:

$$\delta_1 + \delta_3$$

The interaction coefficient δ_3 provides the formal test of H5. A negative and statistically significant δ_3 indicates that the positive GSO–CID association is weaker among heavy-

polluting firms than among non-heavy-polluting firms. The statistical difference between the two conditional associations is evaluated directly using the pooled interaction model.

Separate regressions for heavy-polluting and non-heavy-polluting firms are also reported to describe the association within each subsample. However, differences between the two groups are assessed using the interaction coefficient in the pooled model rather than by comparing whether coefficients are statistically significant in separately estimated regressions.

The industry-based classification captures relatively persistent regulatory, institutional, and legitimacy exposure associated with firms' industry membership. Because it may not fully reflect differences in operating pollution intensity among firms within the same industry, the analysis is supplemented with lagged firm-level carbon intensity. The supplementary specifications interact lagged GSO with the annual mean-centered logarithm of carbon intensity and with firms' annual carbon-intensity percentile ranks. A further specification absorbs industry-by-year fixed effects. These additional models examine whether the industry-based moderating pattern is reproduced when pollution exposure is measured at the firm-year level.

3.4. Estimation Method and Statistical Inference

The principal models are estimated using firm and year fixed effects. Firm fixed effects absorb unobservable and time-invariant corporate characteristics, including persistent organizational culture, production technology, managerial style, industry positioning, and long-term environmental orientation. Year fixed effects capture common shocks affecting all firms in a given year, including macroeconomic fluctuations, regulatory reforms, changes in carbon-disclosure expectations, and national environmental policies.

Standard errors are clustered at the firm level to account for heteroskedasticity and within-firm serial correlation. The principal explanatory variable is lagged by one year in the baseline specification. The three-wave analysis uses green strategic orientation at $t - 2$, reported green-transformation intensity at $t - 1$, and carbon information disclosure at t.

The fixed-effects estimator identifies associations using within-firm variation over time. It does not eliminate confounding from unobserved time-varying factors. Accordingly, the estimated coefficients are interpreted as conditional associations rather than as definitive causal effects.

Because the principal carbon-disclosure variable is bounded between zero and one, a correlated-random-effects fractional logit model is estimated as a robustness test. Following the Mundlak approach, the model includes firm-level means of the time-varying explanatory and control variables together with year indicators. This specification allows the time-varying regressors to be correlated with persistent firm-level heterogeneity. Results from the fractional-response model are reported as average partial effects rather than solely as raw logit coefficients.

A population-averaged generalized estimating equation model with a binomial family, logit link, firm-level clustering, and exchangeable working correlation structure is also estimated as an additional fractional-response check.

For the three-wave models, the indirect, direct, total, and proportional associations are evaluated using 5000 firm-clustered bootstrap replications. The resampling procedure draws firms rather than individual firm-year observations, thereby preserving the dependence structure within each firm's time series.

3.5. Validation and Robustness Strategy

The empirical analysis combines construct validation with a set of robustness tests addressing variable measurement, functional form, reporting propensity, temporal specification, and model structure.

The validity of reported green-transformation intensity is first assessed using non-textual green-investment outcomes. The analysis examines whether RGTI is associated with total, capitalized, expensed, and positive green investment in both the current and following year. RGTI is also reconstructed using green-transformation-related sentence frequency and word density to determine whether the results depend on the principal word-frequency measure.

Alternative measurements are used for both the explanatory and dependent variables. Green strategic orientation is re-estimated using GSO2, the narrower four-item measure described in Section 3.2.2 and Appendix A Table A3. Carbon disclosure is alternatively measured using LnCID and hard carbon information disclosure. Specifications with industry-by-year fixed effects and a sample excluding the principal COVID-19 years are also estimated.

Because CID_std is bounded between zero and one, the linear fixed-effects estimates are supplemented with fractional-response models. The analysis employs a Mundlak correlated-random-effects fractional logit model and a population-averaged generalized estimating equation model with a binomial family and logit link. Average partial effects are reported to facilitate comparison with the linear estimates.

The HardCID analysis addresses the possibility that the baseline results are driven by strategic or qualitative content shared by GSO and the aggregate disclosure index. Both the baseline association and the three-wave indirect pathway are re-estimated using the fractional hard-disclosure measure. Direct, indirect, and total associations are evaluated using 5000 firm-clustered bootstrap replications.

Potential common-source variation is further examined by controlling for firms' general reporting propensity. These specifications include the issuance and length of separate CSR reports and are compared with same-sample fixed-effects benchmarks. Word-based and character-based CSR-report-length measures are used as alternative controls.

Additional temporal specifications use one-year-ahead carbon information disclosure as the dependent variable. A leave-one-out industry-year peer measure of GSO is also used in a supplementary instrumental-variable analysis. Because the exclusion restriction associated with the peer-based instrument cannot be verified directly, the IV estimates are treated as complementary evidence rather than as the principal basis for identification.

Finally, the industry-based moderation analysis is supplemented with firm-level carbon-intensity measures. These specifications examine whether the moderating pattern identified using heavy-polluting-industry status is reproduced using annual mean-centered log carbon intensity, annual carbon-intensity percentile ranks, and models with firm and industry-by-year fixed effects.

4. Research Results

4.1. Descriptive Statistics

Table 3 presents the descriptive statistics for the baseline estimation sample, which comprises 31,625 firm-year observations from 4845 Chinese A-share listed firms over the 2016–2024 period. The mean standardized carbon information disclosure score is 0.287, with a median of 0.240 and a standard deviation of 0.215. The observed values range from 0 to 0.980, indicating considerable variation in the extent of carbon-related information disclosed by listed firms.

The one-year-lagged green strategic orientation measure has a mean of 1.667 and a standard deviation of 1.743. Its values range from 0 to 7, suggesting substantial cross-sectional and intertemporal variation in the extent to which environmental considerations are represented in firms' disclosed strategic orientation. Reported green-transformation intensity has a mean of 2.838 and a standard deviation of 0.947. As this variable is derived from

annual-report word frequency, it reflects the prominence of green-transformation-related attention in corporate reporting rather than directly observed realized transformation.

Table 3. Descriptive statistics.

Variable	N	Mean	SD	Min	Median	Max
Carbon information disclosure	31,625	0.287	0.215	0.000	0.240	0.980
Green strategic orientation	31,625	1.667	1.743	0.000	1.000	7.000
Reported green-transformation intensity	31,625	2.838	0.947	0.000	2.890	6.373
Firm size	31,625	22.372	1.289	20.069	22.179	26.388
Leverage	31,625	0.422	0.203	0.060	0.413	0.921
Return on assets	31,625	0.027	0.072	−0.312	0.033	0.194
Firm growth	31,625	0.126	0.354	−0.601	0.080	1.947
Operating cash flow	31,625	0.048	0.067	−0.154	0.047	0.241
Fixed asset intensity	31,625	0.199	0.150	0.002	0.168	0.660
Board size	31,625	2.097	0.194	1.609	2.197	2.565
Board independence	31,625	0.379	0.053	0.333	0.364	0.571
CEO duality	31,625	0.321	0.467	0.000	0.000	1.000
Largest shareholder ownership	31,625	0.324	0.145	0.080	0.300	0.728
Firm age	31,625	3.061	0.283	2.303	3.091	3.664
State ownership	31,625	0.295	0.456	0.000	0.000	1.000
Big Four auditor	31,625	0.063	0.243	0.000	0.000	1.000
Annual report length	31,625	10.950	0.204	9.501	10.953	12.488

Notes: This table reports descriptive statistics for the baseline fixed-effects estimation sample. The sample contains 31,625 firm-year observations from 4845 Chinese A-share listed firms over the 2016–2024 period. Carbon information disclosure is measured using the standardized CSMAR carbon disclosure index. Green strategic orientation is measured using the one-year-lagged seven-item index. Reported green-transformation intensity is measured as the natural logarithm of one plus the frequency of green-transformation-related words in firms' annual reports. Continuous financial and governance control variables are winsorized at the 1st and 99th percentiles. Bounded, binary, and logarithmically transformed main variables are not additionally winsorized.

The mean values of firm size, leverage, and return on assets are 22.372, 0.422, and 0.027, respectively. The average fixed-asset intensity is 0.199, while the largest shareholder holds approximately 32.4% of the firm's shares. CEO duality is observed in 32.1% of the firm-year observations, state-owned enterprises account for approximately 29.5% of the sample, and 6.3% of the observations involve firms audited by a Big Four accounting firm. The mean logarithmic annual-report length is 10.950.

4.2. Correlation Analysis and Multicollinearity Diagnostics

Table 4 reports the Pearson correlation coefficients between the study variables and the variance inflation factors for the explanatory variables. Carbon information disclosure is positively correlated with lagged green strategic orientation and reported green-transformation intensity, with correlation coefficients of 0.606 and 0.606, respectively. Lagged green strategic orientation is also positively correlated with reported green-transformation intensity, with a coefficient of 0.445. All three correlations are statistically significant at the 1% level.

The positive pairwise associations are consistent with the relationships examined in the subsequent regression analysis. However, these unconditional correlations do not control for firm-specific heterogeneity, common year effects, annual-report length, or the financial and governance characteristics included in the fixed-effects models.

Among the control variables, firm size and annual-report length exhibit relatively strong positive correlations with carbon information disclosure, with coefficients of 0.411 and 0.391, respectively. Big Four auditor status, state ownership, fixed-asset intensity, and firm age are also positively correlated with carbon information disclosure. Firm growth, board independence, and CEO duality are negatively correlated with the

disclosure measure. These correlations describe unconditional relationships and should not be interpreted as partial regression effects.

Table 4. Correlation analysis and variance inflation factors.

Variable	CID	GSO	RGTI	VIF
Carbon information disclosure	1.000	0.606 ***	0.606 ***	—
Green strategic orientation	0.606 ***	1.000	0.445 ***	1.42
Reported green-transformation intensity	0.606 ***	0.445 ***	1.000	1.53
Firm size	0.411 ***	0.379 ***	0.272 ***	2.09
Leverage	0.134 ***	0.103 ***	0.125 ***	1.61
Return on assets	0.068 ***	0.083 ***	0.033 ***	1.68
Firm growth	−0.036 ***	−0.049 ***	−0.026 ***	1.13
Operating cash flow	0.086 ***	0.110 ***	0.060 ***	1.34
Fixed-asset intensity	0.169 ***	0.187 ***	0.266 ***	1.22
Board size	0.113 ***	0.126 ***	0.078 ***	1.77
Board independence	−0.016 ***	−0.019 ***	−0.040 ***	1.58
CEO duality	−0.066 ***	−0.083 ***	−0.055 ***	1.14
Largest shareholder ownership	0.099 ***	0.111 ***	0.061 ***	1.15
Firm age	0.149 ***	0.111 ***	0.124 ***	1.12
State ownership	0.175 ***	0.193 ***	0.094 ***	1.42
Big Four auditor	0.205 ***	0.182 ***	0.060 ***	1.14
Annual report length	0.391 ***	0.265 ***	0.401 ***	1.47
Mean VIF				1.43

Note: This table reports Pearson correlation coefficients between each variable and the three core variables. CID denotes standardized carbon information disclosure; GSO denotes the one-year-lagged seven-item green strategic orientation measure; RGTI denotes reported green-transformation intensity, measured as the natural logarithm of one plus green-transformation-related word frequency in annual reports. CID is the dependent variable and is excluded from the VIF calculation. The VIF statistics are calculated using GSO, RGTI, the control variables, and annual-report length. The sample contains 31,625 firm-year observations. *** indicates statistical significance at 1% levels.

The variance inflation factors range from 1.12 to 2.09, with a mean value of 1.43. Firm size has the largest VIF, at 2.09, followed by return on assets, leverage, board size, and board independence. All values are substantially below conventional multicollinearity thresholds. The correlation between board size and board independence is −0.585, which is the largest pairwise correlation among the control variables, but the corresponding VIF values remain below 2. Therefore, the explanatory variables do not exhibit evidence of severe multicollinearity.

4.3. Baseline Regression Results

Table 5 reports the baseline fixed-effects estimates of the association between green strategic orientation and carbon information disclosure. All specifications include firm and year fixed effects and are estimated using the same baseline sample.

Column (1) includes lagged green strategic orientation without the firm-level control variables. The coefficient of GSO is 0.0300 and is statistically significant at the 1% level. Column (2) adds the financial, governance, ownership, and audit controls. The coefficient declines slightly to 0.0272 but remains statistically significant at the 1% level. Column (3) further controls for annual-report length. The estimated coefficient remains nearly unchanged at 0.0271, with a firm-clustered standard error of 0.0009.

Because the dependent variable ranges from zero to one, the coefficient in Column (3) indicates that a one-point increase in the seven-item GSO index is associated with an increase of approximately 2.71 percentage points in the standardized carbon disclosure score. A one-standard-deviation increase in GSO, equal to 1.743 points, is associated with an increase of approximately 0.0473 in CID, or 4.73 percentage points. This amount

corresponds to approximately 16.49% of the sample mean of CID. The estimated association is therefore statistically significant and economically meaningful.

Table 5. Baseline regression results.

Variables	(1) CID	(2) CID	(3) CID
Green strategic orientation	0.0300 *** (0.0009)	0.0272 *** (0.0009)	0.0271 *** (0.0009)
Firm size	—	0.0663 *** (0.0036)	0.0570 *** (0.0038)
Leverage	—	−0.0901 *** (0.0123)	−0.0927 *** (0.0122)
Return on assets	—	0.0248 (0.0155)	0.0364 ** (0.0154)
Firm growth	—	−0.0080 *** (0.0021)	−0.0092 *** (0.0021)
Operating cash flow	—	0.0312 ** (0.0133)	0.0330 ** (0.0132)
Fixed-asset intensity	—	0.0154 (0.0170)	0.0149 (0.0168)
Board size	—	0.0159 (0.0117)	0.0137 (0.0116)
Board independence	—	0.0104 (0.0353)	0.0099 (0.0350)
CEO duality	—	0.0003 (0.0032)	0.0003 (0.0032)
Largest-shareholder ownership	—	0.1101 *** (0.0245)	0.1110 *** (0.0245)
Firm age	—	−0.1370 *** (0.0366)	−0.1356 *** (0.0365)
State ownership	—	0.0182 *** (0.0065)	0.0201 *** (0.0065)
Big Four auditor	—	0.0227 * (0.0116)	0.0266 ** (0.0115)
Annual report length	—	—	0.0984 *** (0.0116)
Constant	0.2367 *** (0.0016)	−0.8690 *** (0.1398)	−1.7380 *** (0.1708)
Controls	No	Yes	Yes
Annual-report-length control	No	No	Yes
Firm fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Observations	31,625	31,625	31,625
Number of firms	4845	4845	4845
Adjusted R^2	0.7225	0.7329	0.7342
Within R^2	0.0734	0.1087	0.1131

Notes: This table reports firm and year fixed-effects estimates of the association between green strategic orientation and carbon information disclosure. The dependent variable in all columns is the standardized carbon information disclosure score. Green strategic orientation is measured using the one-year-lagged seven-item GSO index. Column (1) includes only GSO and the fixed effects. Column (2) adds the financial, governance, ownership, and audit controls. Column (3) additionally controls for annual-report length. All columns use the same baseline estimation sample. Firm-clustered robust standard errors are reported in parentheses beside the coefficients. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

The stability of the GSO coefficient across the three specifications is also notable. The coefficient decreases by less than 1% when annual-report length is added to the control-variable specification, from 0.0272 to 0.0271. The baseline association is therefore unlikely to be explained solely by mechanical differences in annual-report length.

Among the control variables in Column (3), firm size, profitability, operating cash flow, largest-shareholder ownership, state ownership, Big Four auditor status, and annual-report length are positively associated with carbon information disclosure. Leverage, firm growth, and firm age are negatively associated with disclosure. The coefficients on fixed-asset intensity, board size, board independence, and CEO duality are not statistically significant.

The adjusted R^2 increases from 0.7225 in Column (1) to 0.7342 in Column (3), while the within-firm R^2 increases from 0.0734 to 0.1131. Overall, the results show a stable positive within-firm association between lagged green strategic orientation and subsequent carbon information disclosure. The evidence is consistent with H1.

4.4. Three-Wave Indirect-Pathway Analysis

Table 6 reports the three-wave indirect-pathway analysis, in which green strategic orientation is measured at $t-2$, reported green-transformation intensity is measured at $t-1$, and carbon information disclosure is measured at t. The analysis is based on 20,008

firm-year observations from 3844 firms over the 2018–2024 period. All specifications include firm and year fixed effects, the firm-level controls measured at t − 1, and annual-report length measured at t − 1.

Table 6. Three-wave indirect-pathway analysis.

Panel A. Fixed-Effects Estimates			
Variables	**(1) CID_t**	**(2) $RGTI_{t-1}$**	**(3) CID_t**
GSO_{t-2}	0.0124 *** (0.0011)	0.0287 *** (0.0038)	0.0114 *** (0.0011)
$RGTI_{t-1}$	—	—	0.0349 *** (0.0032)
Controls at (t − 1)	Yes	Yes	Yes
Annual-report length at (t − 1)	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Observations	20,008	20,008	20,008
Number of firms	3844	3844	3844
Adjusted R^2	0.7201	0.8282	0.7237
Within R^2	0.0517	0.0575	0.0639
Panel B. Firm-Clustered Bootstrap Results			
Effect	**Coefficient (Bootstrap SE)**	**Percentile 95% CI**	**Bias-Corrected 95% CI**
Path (a): $GSO(t-2) \rightarrow RGTI(t-1)$	0.028656 *** (0.003916)	[0.020895, 0.036277]	[0.020872, 0.036268]
Path (b): $RGTI_{t-1} \rightarrow CID_t$	0.034855 *** (0.003206)	[0.028773, 0.041264]	[0.028820, 0.041350]
Indirect association	0.000999 *** (0.000178)	[0.000670, 0.001368]	[0.000685, 0.001384]
Direct association	0.011445 *** (0.001125)	[0.009185, 0.013642]	[0.009182, 0.013635]
Total association	0.012444 *** (0.001135)	[0.010135, 0.014659]	[0.010149, 0.014667]
Proportion accounted for	8.03% *** (1.55%)	[5.35%, 11.38%]	[5.41%, 11.50%]

Notes: Panel A reports firm and year fixed-effects estimates using a three-wave temporal specification. Green strategic orientation is measured at t − 2, reported green-transformation intensity is measured at t − 1, and carbon information disclosure is measured at t. The control variables and annual-report length are measured at t − 1. Firm-clustered robust standard errors are reported in parentheses beside the coefficients. Panel B reports results from 5000 firm-clustered Bootstrap replications. The indirect association is calculated as the product of Path a and Path b. The proportion accounted for is calculated as the indirect association divided by the total association. Percentile and bias-corrected 95% confidence intervals are reported. *** indicates statistical significance at 1% levels.

Panel A presents the fixed-effects estimates. Column (1) reports the total association between green strategic orientation at t − 2 and carbon information disclosure at t. The coefficient on GSO_{t-2} is 0.0124 and statistically significant at the 1% level. This result indicates that a stronger reported green strategic orientation is positively associated with carbon information disclosure two years later.

Column (2) examines the association between GSO_{t-2} and reported green-transformation intensity at t − 1. The coefficient is 0.0287 and statistically significant at the 1% level. Thus, a higher level of reported green strategic orientation predicts greater subsequent attention to green transformation in the firm's annual reporting. This result is consistent with H2.

Column (3) includes both GSO_{t-2} and reported green-transformation intensity at t − 1. The coefficient on reported green-transformation intensity is 0.0349 and statistically significant at the 1% level, while the coefficient on GSO_{t-2} remains positive and significant at 0.0114. These estimates indicate that reported green-transformation intensity is positively associated with subsequent carbon information disclosure after controlling for prior green strategic orientation. This result is consistent with H3.

Panel B reports the firm-clustered Bootstrap results based on 5000 replications. The estimated indirect association is 0.000999, with a Bootstrap standard error of 0.000178. The percentile 95% confidence interval is [0.000670, 0.001368], and the bias-corrected confidence interval is [0.000685, 0.001384]. Both intervals exclude zero. The direct association remains positive and statistically significant at 0.011445, while the total association is 0.012444.

The proposed indirect pathway accounts for approximately 8.03% of the total GSO–CID association. Its bias-corrected 95% confidence interval ranges from 5.41% to 11.50%. The results are therefore consistent with partial statistical mediation and provide support for H4. However, the estimated proportion is economically modest, indicating that most of the GSO–CID association is statistically associated with channels other than the reported green-transformation pathway examined in this study.

The economic magnitude of the three-wave estimates is also considered. The standard deviation of GSO_{t-2} in the three-wave sample is 1.682. Accordingly, a one-standard-deviation increase in GSO_{t-2} is associated with an increase of approximately 0.0209 in CID_t, equivalent to 2.09 percentage points. This represents approximately 6.63% of the mean CID value in the three-wave sample. The corresponding indirect association is approximately 0.00168, or 0.17 percentage points.

The temporal separation among the three variables improves the ordering of the proposed pathway relative to the contemporaneous specification. Nevertheless, it does not eliminate possible confounding from unobserved time-varying factors that may jointly affect reported green-transformation intensity and carbon information disclosure. The results are therefore interpreted as a temporally ordered statistical indirect association rather than as evidence of causal mediation.

4.5. Validation of Reported Green-Transformation Intensity

Table 7 examines the association between reported green-transformation intensity and firm-level green investment. The green-investment measures are obtained from a separate licensed CSMAR green-investment database and are constructed independently of the annual-report textual data used to measure RGTI. They therefore provide non-textual indicators of firms' observable environmental resource allocation. All specifications include green strategic orientation, the full set of firm-level controls, annual-report length, firm fixed effects, and year fixed effects. Standard errors are clustered at the firm level.

Panel A reports the contemporaneous results. Reported green-transformation intensity is positively associated with total green investment. The estimated coefficient is 0.4133 and is statistically significant at the 1% level. A similar result is obtained for capitalized green investment, for which the coefficient is 0.3843 and statistically significant at the 1% level. The coefficient on expensed green investment is positive but statistically insignificant.

Table 7. Validation of reported green-transformation intensity using green investment.

Panel A. Contemporaneous Green-Investment Outcomes					
Variables	**(1) Total Green Investment**	**(2) Capitalized Green Investment**	**(3) Expensed Green Investment**	**(4) Green Investment Intensity**	**(5) Positive Green Investment**
Reported green-transformation intensity	0.4133 *** (0.1003)	0.3843 *** (0.1000)	0.0928 (0.0604)	0.0001 (0.0002)	0.0242 *** (0.0059)
Green strategic orientation	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes
Annual-report-length control	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	31,625	31,625	31,625	31,625	31,625
Number of firms	4845	4845	4845	4845	4845
Adjusted R^2	0.6385	0.5644	0.7648	0.5247	0.6112
Within R^2	0.0135	0.0130	0.0039	0.0117	0.0092

Table 7. *Cont.*

Panel B. One-Year-Ahead Green-Investment Outcomes					
Variables	**(1) Total Green Investment$_{t+1}$**	**(2) Capitalized Green Investment$_{t+1}$**	**(3) Expensed Green Investment$_{t+1}$**	**(4) Green Investment/Total Assets$_{t+1}$**	**(5) Positive Green Investment$_{t+1}$**
Reported green-transformation intensity	0.2997 *** (0.0968)	0.2754 *** (0.0972)	0.1221 ** (0.0541)	0.0003 (0.0002)	0.0155 *** (0.0057)
Green strategic orientation	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes
Annual-report-length control	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	31,537	31,537	31,537	31,537	31,537
Number of firms	4840	4840	4840	4840	4840
Adjusted R^2	0.6513	0.5730	0.7899	0.5133	0.6261
Within R^2	0.0063	0.0065	0.0024	0.0051	0.0041

Panel C. Alternative Measures of Reported Green-Transformation Intensity		
Variables	**(1) Sentence-Frequency RGTI**	**(2) Word-Density RGTI**
Alternative RGTI measure	0.4445 *** (0.1088)	0.0850 *** (0.0257)
Dependent variable	Total green investment	Total green investment
Green strategic orientation	Yes	Yes
Controls	Yes	Yes
Annual-report-length control	Yes	Yes
Firm fixed effects	Yes	Yes
Year fixed effects	Yes	Yes
Observations	31,625	31,625
Number of firms	4845	4845
Adjusted R^2	0.6385	0.6384
Within R^2	0.0135	0.0132

Notes: Panels A and B report firm and year fixed-effects estimates using contemporaneous and one-year-ahead green-investment outcomes, respectively. Total, capitalized, and expensed green investment are transformed using the inverse hyperbolic sine function. Green investment/total assets is measured as total green investment divided by total assets. Positive green investment is an indicator equal to one when positive green investment is identified and zero otherwise; the corresponding specifications are estimated as fixed-effects linear probability models. Panel C replaces the baseline word-frequency measure with the natural logarithm of one plus green-transformation-related sentence frequency and green-transformation-related word frequency per 10,000 annual-report words. All models control for green strategic orientation, firm-level financial and governance variables, and annual-report length. Firm-clustered robust standard errors are reported in parentheses beside the coefficients. **, and *** indicate statistical significance at the 5%, and 1% levels, respectively. The green-investment outcomes are obtained from the Listed Companies Green Environmental Investment Summary Table in the CSMAR Listed Companies Green Investment Database. This database is independent of the annual-report textual database used to construct RGTI. Capitalized green investment includes environmentally related amounts recognized in construction in progress, fixed assets, and development expenditures. Expensed green investment includes environmentally related amounts recognized in administrative and research-and-development expenses. Total green investment is constructed as the sum of the capitalized and expensed components. Monetary variables are transformed using the inverse hyperbolic sine function. Firm-clustered robust standard errors are reported in parentheses.

Reported green-transformation intensity is also positively associated with the likelihood of observing positive green investment. The coefficient is 0.0242 and statistically significant at the 1% level, indicating that a one-unit increase in reported green-transformation intensity is associated with an approximately 2.42-percentage-point increase in the probability of positive green investment. By contrast, the coefficient on green investment divided by total assets is small and statistically insignificant. The contemporaneous results therefore

relate primarily to the absolute scale and occurrence of green investment rather than to green-investment intensity relative to firm size.

Panel B uses one-year-ahead green-investment outcomes. Reported green-transformation intensity is positively associated with subsequent total green investment and subsequent capitalized green investment, with coefficients of 0.2997 and 0.2754, respectively. Both estimates are statistically significant at the 1% level. The coefficient on subsequent expensed green investment is 0.1221 and statistically significant at the 5% level. Reported green-transformation intensity is also positively associated with the probability of observing positive green investment in the following year. The coefficient of 0.0155 indicates an increase of approximately 1.55 percentage points. The asset-scaled green-investment measure remains statistically insignificant.

Panel C replaces the baseline word-frequency measure with two alternative textual measures. Green-transformation-related sentence frequency is positively associated with total green investment, with a coefficient of 0.4445 that is significant at the 1% level. The coefficient on green-transformation-related word density is also positive and significant at the 1% level. The relationship between reported green-transformation intensity and green investment is therefore not confined to the use of raw word frequency.

The adjusted R^2 values range from 0.5247 to 0.7899 across the green-investment models. The within R^2 values are considerably smaller, ranging from 0.0024 to 0.0135, reflecting the limited proportion of within-firm annual variation in green investment explained by the time-varying regressors after firm fixed effects are absorbed. This pattern is not unusual in firm fixed-effects models with persistent investment outcomes.

4.6. Robustness Analyses

To assess the sensitivity of the main findings, this section employs alternative variable measurements, more demanding fixed-effects structures, sample-period restrictions, fractional-response estimators, alternative carbon-disclosure components, and additional controls for firms' general reporting propensity.

4.6.1. Alternative Measurements and Estimation Methods

Table 8 examines whether the positive association between green strategic orientation and carbon information disclosure is sensitive to alternative measurements and estimation methods.

Panel A reports the fixed-effects results. Column (1) replaces the standardized carbon information disclosure measure with the natural logarithm of one plus the original disclosure score. The coefficient on lagged green strategic orientation is 0.0698 and statistically significant at the 1% level. The result indicates that the baseline finding is not dependent on scaling the carbon disclosure index between zero and one.

Column (2) replaces the seven-item GSO measure with the narrower four-item measure, which focuses on environmental philosophy, environmental objectives, environmental management systems, and ISO 14000 certification. The coefficient on the alternative GSO measure is 0.0333 and statistically significant at the 1% level. The positive association therefore remains when green strategic orientation is measured using only its core strategic and institutional components.

Column (3) absorbs firm fixed effects and industry-by-year fixed effects. This specification accounts for time-varying shocks that may affect firms within the same industry, including changes in environmental regulation, industry demand, technological conditions, and disclosure practices. The coefficient on lagged GSO remains positive and statistically significant at 0.0266.

Table 8. Alternative measurements and estimation methods.

Panel A. Alternative Measurements and Fixed-Effects Specifications				
Variables	**(1) Alternative CID**	**(2) Alternative GSO**	**(3) Industry–Year FE**	**(4) Excluding 2020–2022**
Green strategic orientation	0.0698 *** (0.0032)	0.0333 *** (0.0012)	0.0266 *** (0.0009)	0.0325 *** (0.0011)
Dependent variable	LnCID	CID_std	CID_std	CID_std
GSO measure	GSO1	GSO2	GSO1	GSO1
Firm-level controls	Yes	Yes	Yes	Yes
Annual-report-length control	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	No	Yes
Industry–year fixed effects	No	No	Yes	No
Excluding 2020–2022	No	No	No	Yes
Observations	31,625	31,625	31,593	20,467
Number of firms	4845	4845	4844	4822
Adjusted R^2	0.7032	0.7304	0.7418	0.7494
Within R^2	0.0449	0.1004	0.1083	0.1593
Panel B. Fractional-Response Estimates				
Statistics	**(1) Mundlak CRE: GSO1**	**(2) Mundlak CRE: GSO2**	**(3) Mundlak-Adjusted GEE**	
Average partial effect	0.0204 *** (0.0007)	0.0266 *** (0.0011)	0.0195 *** (0.0007)	
95% confidence interval	[0.0189, 0.0218]	[0.0245, 0.0287]	[0.0180, 0.0209]	
One-SD change in CID	0.0355	0.0326	0.0339	
GSO measure	GSO1	GSO2	GSO1	
Firm-level means included	Yes	Yes	Yes	
Year indicators	Yes	Yes	Yes	
Working correlation structure	—	—	Exchangeable	
Observations	31,625	31,625	31,625	
Number of firms	4845	4845	4845	
Pseudo R^2	0.1114	0.1097	—	

Notes: Panel A reports fixed-effects estimates using alternative variable measurements, fixed-effects structures, and sample-period restrictions. Column (1) uses the natural logarithm of one plus the original carbon information disclosure score. Column (2) replaces the seven-item GSO1 measure with the four-item GSO2 measure. Column (3) absorbs firm and industry-by-year fixed effects. Column (4) excludes observations from 2020 to 2022. Panel B reports average partial effects from fractional-response models. Columns (1) and (2) use Mundlak correlated-random-effects fractional logit models. Column (3) uses a population-averaged GEE model with a binomial family, logit link, exchangeable working correlation structure, and Mundlak firm-level means. Firm-clustered robust standard errors are reported in parentheses. *** indicates statistical significance at 1% levels.

Column (4) excludes observations from 2020 to 2022 to reduce the possibility that disruptions during the COVID-19 period drive the baseline results. The estimated coefficient is 0.0325 and remains statistically significant at the 1% level. The positive GSO–CID association is therefore not confined to the pandemic period.

Panel B accounts for the fractional nature of the standardized CID measure. Because *CID_std* is bounded between zero and one, the linear fixed-effects model may not fully reflect the conditional-mean structure of the dependent variable. Columns (1) and (2) therefore estimate Mundlak correlated-random-effects fractional logit models and report average partial effects rather than raw logit coefficients.

For the seven-item GSO measure, the average partial effect is 0.0204 and statistically significant at the 1% level. This estimate indicates that a one-point increase in lagged GSO is associated with an approximately 2.04-percentage-point increase in the conditional mean of CID. Given the standard deviation of the GSO measure, a one-standard-deviation increase is associated with an approximately 3.55-percentage-point increase in CID.

When the four-item GSO measure is used, the average partial effect is 0.0266 and statistically significant at the 1% level. A one-standard-deviation increase in this measure corresponds to an approximately 3.26-percentage-point increase in CID.

Column (3) estimates a population-averaged GEE model with a binomial family, logit link, exchangeable working correlation structure, and Mundlak firm-level means. The average partial effect is 0.0195 and statistically significant at the 1% level. A one-standard-deviation increase in the seven-item GSO measure is associated with an approximately 3.39-percentage-point increase in CID.

4.6.2. Hard Carbon Information Disclosure

The aggregate carbon information disclosure index contains both qualitative and quantitative disclosure items. Because green strategic orientation and qualitative carbon disclosure may partly reflect overlapping strategic language, this section replaces the aggregate disclosure measure with the hard carbon information disclosure component. Hard disclosure emphasizes quantitative, performance-oriented, and relatively verifiable carbon information, thereby reducing concerns that the baseline association is driven primarily by common strategy-related disclosure content.

Panel A of Table 9 reports the results using alternative specifications of hard carbon information disclosure. Column (1) uses the hard disclosure score divided by its theoretical maximum of 28. The coefficient on the seven-item green strategic orientation measure is 0.0251 and statistically significant at the 1% level. A one-point increase in lagged GSO is therefore associated with an approximately 2.51-percentage-point increase in the hard disclosure fraction. Based on the sample standard deviation of GSO, a one-standard-deviation increase corresponds to an increase of approximately 4.38 percentage points.

Column (2) replaces the seven-item GSO measure with the narrower four-item measure. The coefficient remains positive and statistically significant, at 0.0300. A one-standard-deviation increase in the four-item GSO measure is associated with an approximately 3.67-percentage-point increase in the hard disclosure fraction.

Column (3) uses the natural logarithm of one plus the original hard disclosure score. The coefficient on lagged GSO is 0.0837 and statistically significant at the 1% level. The result indicates that the positive association is not dependent on scaling the hard disclosure score between zero and one.

Columns (4) and (5) account for the fractional distribution of the dependent variable using Mundlak correlated-random-effects fractional logit models. The average partial effect of the seven-item GSO measure is 0.0158, while the corresponding effect of the four-item measure is 0.0220. Both estimates are statistically significant at the 1% level. A one-standard-deviation increase in the respective GSO measures is associated with an increase of approximately 2.76 and 2.70 percentage points in the conditional mean of the hard disclosure fraction.

Panel B replicates the three-wave indirect-pathway analysis using hard carbon information disclosure as the outcome. Green strategic orientation is measured at $t-2$, reported green-transformation intensity at $t-1$, and hard carbon disclosure at t. The coefficient for Path a is 0.0287, while the coefficient for Path b is 0.0266. Both estimates are statistically significant at the 1% level.

The estimated indirect association is 0.000763, with a Bootstrap standard error of 0.000148. The percentile 95% confidence interval is [0.000492, 0.001079], and the bias-corrected confidence interval is [0.000505, 0.001093]. Both intervals exclude zero. The direct association remains positive and statistically significant at 0.013079, while the total association is 0.013842.

Table 9. Results using hard carbon information disclosure.

Panel A. Alternative Hard-Disclosure Specifications					
Variables	**(1) HardCID Fraction**	**(2) HardCID Fraction**	**(3) LnHardCID**	**(4) CRE Fractional Logit**	**(5) CRE Fractional Logit**
GSO coefficient/average partial effect	0.0251 *** (0.0010)	0.0300 *** (0.0013)	0.0837 *** (0.0039)	0.0158 *** (0.0007)	0.0220 *** (0.0010)
95% confidence interval	[0.0232, 0.0270]	[0.0274, 0.0325]	[0.0761, 0.0914]	[0.0144, 0.0172]	[0.0200, 0.0240]
GSO measure	GSO1	GSO2	GSO1	GSO1	GSO2
Estimate reported	FE coefficient	FE coefficient	FE coefficient	Average partial effect	Average partial effect
One-SD change in HardCID	0.0438	0.0367	—	0.0276	0.0270
Firm-level controls	Yes	Yes	Yes	Yes	Yes
Annual-report-length control	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	No	No
Firm-level means included	No	No	No	Yes	Yes
Year effects/indicators	Yes	Yes	Yes	Yes	Yes
Observations	31,625	31,625	31,625	31,625	31,625
Number of firms	4845	4845	4845	4845	4845
Adjusted R^2	0.6545	0.6496	0.6700	—	—
Within R^2	0.0966	0.0839	0.0517	—	—
Pseudo R^2	—	—	—	0.1466	0.1454
Panel B. Three-Wave Indirect Pathway Using Hard Carbon Disclosure					
Effect	**Coefficient (Bootstrap SE)**	**Percentile 95% CI**	**Bias-Corrected 95% CI**		
Path (a): $GSO(t-2) \rightarrow RGTI(t-1)$	0.028656 *** (0.003917)	[0.020895, 0.036277]	[0.020872, 0.036268]		
Path (b): $RGTI(_{t-1}) \rightarrow HardCID(_t)$	0.026625 *** (0.003205)	[0.020425, 0.032971]	[0.020644, 0.033109]		
Indirect association	0.000763 *** (0.000148)	[0.000492, 0.001079]	[0.000505, 0.001093]		
Direct association	0.013079 *** (0.001243)	[0.010622, 0.015569]	[0.010638, 0.015583]		
Total association	0.013842 *** (0.001246)	[0.011383, 0.016317]	[0.011384, 0.016318]		
Proportion accounted for	5.51% *** (1.16%)	[3.52%, 8.00%]	[3.54%, 8.07%]		
Observations	20,008	20,008	20,008		
Number of firms	3844	3844	3844		
Bootstrap replications	5000	5000	5000		

Notes: Panel A reports fixed-effects and fractional-response estimates using hard carbon information disclosure. *HardCID_frac* is calculated as the original hard disclosure score divided by its theoretical maximum of 28. LnHardCID is calculated as the natural logarithm of one plus the original hard disclosure score. Columns (1)–(3) report firm and year fixed-effects estimates. Columns (4) and (5) report average partial effects from Mundlak correlated-random-effects fractional logit models. One-SD change is calculated by multiplying the estimated coefficient or average partial effect by the sample standard deviation of the corresponding GSO measure. Panel B reports the results of 5000 firm-clustered Bootstrap replications using a three-wave temporal specification. Green strategic orientation is measured at t − 2, reported green-transformation intensity at t − 1, and hard carbon disclosure at t. The indirect association is calculated as the product of Paths a and b, and the proportion accounted for is calculated as the indirect association divided by the total association. Firm-clustered robust standard errors are reported in parentheses. *** indicates statistical significance at 1% levels.

The reported green-transformation pathway accounts for approximately 5.51% of the total association between green strategic orientation and hard carbon disclosure. Its bias-corrected 95% confidence interval ranges from 3.54% to 8.07%. In economic terms, a one-standard-deviation increase in GSO_{t-2} is associated with an approximately 2.33-percentage-point increase in the hard disclosure fraction. The corresponding indirect association is approximately 0.13 percentage points.

These results indicate that the positive GSO–CID association and the temporally ordered indirect pathway are not confined to qualitative or strategy-oriented carbon disclosure. Nevertheless, the indirect proportion remains modest, suggesting that most of the association

between green strategic orientation and hard carbon disclosure operates through channels other than the reported green-transformation pathway examined here. The results are interpreted as statistical associations rather than as evidence of causal mediation.

4.6.3. Controlling for General Reporting Propensity

A remaining concern is that the observed association between green strategic orientation and carbon information disclosure may partly reflect firms' general propensity to produce extensive non-financial reports. Firms with stronger reporting cultures may be more likely to discuss environmental strategy in their annual reports and to disclose more carbon-related information, even in the absence of a distinct GSO–CID relationship. Table 10 therefore introduces controls for firms' broader CSR-reporting behavior.

Table 10. Controlling for general reporting propensity.

Variables	(1) Same-Sample Benchmark	(2) CSR Word-Count Controls	(3) Alternative GSO	(4) CSR Character-Count Controls
Lagged GSO1	0.0260 *** (0.0010)	0.0083 *** (0.0010)	—	0.0085 *** (0.0010)
Lagged GSO2	—	—	0.0115 *** (0.0013)	—
95% CI of focal GSO coefficient	[0.0240, 0.0279]	[0.0063, 0.0102]	[0.0089, 0.0141]	[0.0066, 0.0105]
Firm-level controls	Yes	Yes	Yes	Yes
Annual-report-length control	Yes	Yes	Yes	Yes
Lagged CSR-report indicator	No	Yes	Yes	Yes
Lagged CSR-report length	No	Word count	Word count	Character count
Firm fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Observations	25,530	25,530	25,530	25,530
Number of firms	4441	4441	4441	4441
Adjusted R^2	0.7349	0.7570	0.7571	0.7567
Within R^2	0.1058	0.1807	0.1811	0.1796

Notes: This table reports firm and year fixed-effects estimates after controlling for firms' general reporting propensity. Column (1) re-estimates the baseline model using the common sample employed in all four columns. Column (2) adds an indicator equal to one when the firm issued a separate CSR report in the preceding year and the natural logarithm of one plus the preceding year's CSR-report word count. Column (3) replaces the seven-item GSO1 measure with the four-item GSO2 measure. Column (4) replaces CSR-report word count with the natural logarithm of one plus CSR-report character count. The CSR-report variables are measured at $t-1$. Firms without a separate CSR report are assigned zero report length and are distinguished by the CSR-report indicator. All specifications include the full set of firm-level controls, annual-report length, firm fixed effects, and year fixed effects. Firm-clustered robust standard errors are reported in parentheses beside the coefficients. *** indicates statistical significance at 1% levels.

To ensure comparability, all four specifications are estimated using the same sample of 25,530 firm-year observations from 4441 firms. Column (1) re-estimates the baseline fixed-effects model using this restricted sample. The coefficient on lagged GSO1 is 0.0260 and statistically significant at the 1% level. This estimate is close to the full-sample baseline coefficient of 0.0271, indicating that the change in sample composition has little influence on the baseline result.

Column (2) adds an indicator for whether the firm issued a separate CSR report in the preceding year and the logarithm of the preceding year's CSR-report word count. The coefficient on lagged GSO1 declines to 0.0083 but remains statistically significant at the 1% level. Relative to the same-sample benchmark, the coefficient decreases by 68.17%. This substantial attenuation indicates that general reporting propensity accounts for an important part of the observed GSO–CID association.

Despite the reduction in magnitude, the remaining association is economically non-trivial. A one-standard-deviation increase in lagged GSO1 is associated with an increase of approximately 0.0147 in the standardized CID measure after the CSR-reporting controls are included, equivalent to approximately 1.47 percentage points.

Column (3) replaces the seven-item GSO measure with the narrower four-item GSO2 measure while retaining the lagged CSR-report indicator and word-count control. The coefficient on GSO2 is 0.0115 and statistically significant at the 1% level. Column (4) replaces CSR-report word count with CSR-report character count. The coefficient on GSO1 is 0.0085 and remains statistically significant at the 1% level.

The augmented specifications also display higher explanatory power. The adjusted R^2 increases from 0.7349 in the same-sample benchmark to approximately 0.7570 after the CSR-reporting controls are introduced, while the within R^2 increases from 0.1058 to approximately 0.1807. These changes indicate that broader reporting behavior explains a meaningful portion of within-firm variation in carbon information disclosure.

4.7. Supplementary Temporal and Instrumental-Variable Analyses

The three-wave analysis in Section 4.4 provides the main evidence regarding the temporal ordering of green strategic orientation, reported green-transformation intensity, and carbon information disclosure. This section presents two supplementary analyses. The first uses one-year-ahead carbon information disclosure as the dependent variable. The second employs a leave-one-out industry-year peer measure of green strategic orientation as an instrumental variable. These analyses provide additional evidence on the temporal stability and robustness of the main association. Nevertheless, they do not fully eliminate concerns regarding unobserved time-varying factors or the exclusion restriction of the instrument and are therefore not interpreted as definitive causal identification.

4.7.1. Additional Temporal Specifications

Table 11 reports additional temporal specifications using carbon information disclosure at t + 1 as the dependent variable. Green strategic orientation, reported green-transformation intensity, the control variables, and annual-report length are measured at t. All three models use the same sample of 25,530 firm-year observations from 4441 firms.

Table 11. Additional temporal specifications.

Variables	(1) CID_{t+1}	(2) CID_{t+1}	(3) CID_{t+1}
Green strategic orientation$_t$	0.0260 *** (0.0010)	—	0.0243 *** (0.0010)
Reported green-transformation intensity$_t$	—	0.0393 *** (0.0028)	0.0298 *** (0.0026)
Firm-level controls	Yes	Yes	Yes
Annual-report-length control	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Observations	25,530	25,530	25,530
Number of firms	4441	4441	4441
Adjusted R^2	0.7326	0.7221	0.7355
Within R^2	0.0982	0.0627	0.1081

Notes: This table reports firm and year fixed-effects estimates using one-year-ahead carbon information disclosure as the dependent variable. Green strategic orientation, reported green-transformation intensity, firm-level controls, and annual-report length are measured at t, while carbon information disclosure is measured at t + 1. The explanatory-variable years cover 2016–2023, and the corresponding outcome years cover 2017–2024. All columns use the same estimation sample. Firm-clustered robust standard errors are reported in parentheses. *** indicates statistical significance at 1% levels.

Column (1) examines green strategic orientation separately. The coefficient on GSO_t is 0.0260 and statistically significant at the 1% level, indicating that stronger green strategic orientation is positively associated with carbon information disclosure in the following year.

Column (2) examines reported green-transformation intensity. The coefficient on $RGTI_t$ is 0.0393 and statistically significant at the 1% level. Firms that devote greater annual-report attention to green transformation therefore tend to report more carbon-related information in the subsequent year.

Column (3) includes both variables simultaneously. The coefficient on GSO_t remains positive and statistically significant at 0.0243, while the coefficient on $RGTI_t$ is 0.0298 and also statistically significant at the 1% level. These results indicate that green strategic orientation and reported green-transformation intensity contain distinct information associated with subsequent carbon disclosure.

The joint specification has an adjusted R^2 of 0.7355 and a within R^2 of 0.1081. Overall, the results show that the positive associations identified in the main analysis are not confined to carbon disclosure measured in the same reporting period.

The forward-looking specifications improve the temporal ordering of the variables but do not rule out the possibility that unobserved time-varying factors jointly affect green strategic orientation, reported green-transformation intensity, and subsequent carbon disclosure. The results are therefore interpreted as supplementary temporal associations rather than as causal effects.

4.7.2. Supplementary Instrumental-Variable Analysis

To further assess the potential influence of endogeneity, a supplementary instrumental-variable analysis is conducted using the leave-one-out industry-year average of lagged green strategic orientation as an instrument for firm-level GSO. The focal firm is excluded from the construction of the peer measure, thereby avoiding a mechanical correlation between the endogenous variable and the instrument. The underlying rationale is that firms may adjust their environmental strategic orientation in response to prevailing practices and strategic developments among industry peers.

The detailed results are reported in Appendix A Table A6. The first-stage coefficient on peer GSO is 0.1669 and statistically significant at the 1% level. The excluded-instrument F-statistic is 23.39, exceeding the conventional threshold of 10. The Kleibergen–Paap rk LM statistic is 24.47 with a p-value below 0.001, and the Kleibergen–Paap rk Wald F-statistic is 23.39. These diagnostic statistics indicate that the instrument is relevant and that the specification is not underidentified.

Column (2) reports the conventional fixed-effects estimate using the same sample as the IV model. The coefficient on lagged GSO is 0.0271 and statistically significant at the 1% level, closely matching the baseline estimate. Column (3) reports the IV-2SLS result. The coefficient on instrumented GSO is 0.0557, with a standard error of 0.0230, and is statistically significant at the 5% level. The Anderson–Rubin test also rejects the null of no effect at the 5% level, with a p-value of 0.0233.

The endogeneity test yields a statistic of 1.53 and a p-value of 0.2161, indicating that the null hypothesis that lagged GSO may be treated as exogenous cannot be rejected. Accordingly, the IV estimate is not statistically distinguishable from the corresponding fixed-effects estimate. Taken together, the IV results are directionally consistent with the baseline findings and provide supplementary evidence of a positive association between green strategic orientation and carbon information disclosure.

As with peer-based instruments more generally, the interpretation relies on the assumption that the leave-one-out industry-year peer measure affects the focal firm's carbon disclosure primarily through its own green strategic orientation. Because this exclusion restriction cannot be tested directly, the IV results are regarded as complementary evidence rather than as stand-alone causal identification.

4.8. Moderating Role of Pollution Exposure

The relationship between green strategic orientation and carbon information disclosure may vary with firms' pollution exposure. Firms operating in pollution-intensive industries face stronger environmental scrutiny and more demanding disclosure expectations, but they may also face greater operational complexity and higher costs in converting strategic commitments into detailed carbon reporting. Table 12 examines this possibility using both an industry-based heavy-pollution classification and firm-level carbon intensity.

Table 12. Pollution exposure and the GSO–CID association.

Panel A. Industry-Based Heavy-Pollution Classification			
Variables	**(1) Full-Sample Interaction**	**(2) Non-Heavy-Polluting Firms**	**(3) Heavy-Polluting Firms**
Lagged green strategic orientation	0.0290 *** (0.0010)	0.0287 *** (0.0011)	0.0199 *** (0.0016)
Heavy-polluting industry	0.0338 *** (0.0119)	—	—
GSO × Heavy-polluting industry	−0.0072 *** (0.0018)	—	—
Conditional GSO effect: heavy-polluting firms	0.0218 *** (0.0016)	—	—
Firm-level controls	Yes	Yes	Yes
Annual-report-length control	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Observations	31,625	24,998	6577
Number of firms	4845	3950	1003
Adjusted R^2	0.7346	0.7258	0.7387
Within R^2	0.1144	0.1137	0.0917
Difference-test (p)-value	0.0001	—	—
Panel B. Firm-Level Carbon-Intensity Measures			
Variables	**(1) Year-Centered Log Carbon Intensity**	**(2) Annual Carbon-Intensity Percentile**	**(3) Log Carbon Intensity with Industry–Year FE**
Lagged green strategic orientation	0.0259 *** (0.0010)	0.0259 *** (0.0010)	0.0253 *** (0.0010)
Carbon-intensity measure	0.0001 (0.0097)	−0.0007 (0.0037)	0.0030 (0.0096)
GSO × Carbon-intensity measure	−0.0006 (0.0036)	0.0006 (0.0016)	−0.0017 (0.0036)
95% CI of interaction	[−0.0076, 0.0064]	[−0.0025, 0.0037]	[−0.0088, 0.0054]
Marginal GSO effect at low exposure	0.0261 *** (0.0014)	0.0257 *** (0.0012)	0.0258 *** (0.0014)
Marginal GSO effect at mean exposure	0.0259 *** (0.0010)	0.0259 *** (0.0010)	0.0253 *** (0.0010)
Marginal GSO effect at high exposure	0.0258 *** (0.0015)	0.0262 *** (0.0012)	0.0248 *** (0.0015)
Firm-level controls	Yes	Yes	Yes
Annual-report-length control	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	No
Industry–year fixed effects	No	No	Yes
Observations	23,775	23,775	23,733
Number of firms	3385	3385	3385
Adjusted R^2	0.7257	0.7257	0.7338
Within R^2	0.1064	0.1064	0.1059

Notes: Panel A reports firm and year fixed-effects estimates based on the industry-level heavy-pollution classification reported in Appendix A Table A5. Column (1) estimates the pooled interaction model. The coefficient on lagged GSO represents the association among non-heavy-polluting firms, while the conditional association among heavy-polluting firms is calculated as the sum of the GSO coefficient and the interaction coefficient. Columns (2) and (3) report subsample estimates. The difference-test p-value is based on the interaction coefficient in the pooled model. Panel B uses lagged firm-level carbon intensity. Carbon intensity is adjusted at the annual 99th percentile before transformation. Columns (1) and (3) use the annual mean-centered logarithm of carbon intensity. Column (2) uses the centered annual carbon-intensity percentile. Low, mean, and high exposure correspond to −0.3, 0, and 0.3 in Columns (1) and (3), and −0.4, 0, and 0.4 in Column (2). Column (3) absorbs firm and industry-by-year fixed effects. All models include the full set of firm-level controls and annual-report length. Firm-clustered robust standard errors are reported in parentheses beside the coefficients. *** indicates statistical significance at 1% levels.

Panel A reports the results based on the industry classification. Column (1) estimates a pooled interaction model. The coefficient on lagged GSO is 0.0290 and statistically significant at the 1% level. Because non-heavy-polluting firms constitute the reference group, this coefficient represents the estimated GSO–CID association among those firms.

The interaction between lagged GSO and the heavy-polluting-industry indicator is −0.0072 and statistically significant at the 1% level. The formal difference test produces an F-statistic of 15.02 and a *p*-value of 0.0001. The conditional GSO coefficient among heavy-polluting firms is 0.0218 and remains statistically significant at the 1% level. Relative to the estimated association among non-heavy-polluting firms, the conditional association is approximately 24.75% smaller.

Columns (2) and (3) report separate subsample estimates. The coefficient on lagged GSO is 0.0287 among non-heavy-polluting firms and 0.0199 among heavy-polluting firms. Both coefficients are statistically significant at the 1% level. The subsample estimates are therefore consistent with the pooled interaction model: green strategic orientation is positively associated with carbon disclosure in both groups, but the association is weaker among firms classified as operating in heavy-polluting industries.

Panel B supplements the industry classification with firm-level carbon intensity. The carbon-intensity data are lagged by one year, and the upper tail is adjusted using annual 99th-percentile values. The first two specifications use 23,775 firm-year observations from 3385 firms. The specification with industry-by-year fixed effects uses 23,733 observations from the same number of firms.

Column (1) interacts lagged GSO with the annual mean-centered logarithm of carbon intensity. The interaction coefficient is −0.0006 and statistically insignificant. Column (2) uses firms' annual carbon-intensity percentiles and produces an interaction coefficient of 0.0006, which is also insignificant. Column (3) absorbs firm and industry-by-year fixed effects. The interaction coefficient remains statistically insignificant at −0.0017.

The estimated marginal association of GSO changes very little across the selected carbon-intensity levels. In Column (1), the marginal GSO coefficients are 0.0261, 0.0259, and 0.0258 at low, mean, and high levels of mean-centered log carbon intensity. In the percentile specification, the corresponding coefficients are 0.0257, 0.0259, and 0.0262. The results remain similarly stable after absorbing industry-by-year fixed effects.

5. Discussion

5.1. Green Strategic Orientation and the Internal Foundations of Carbon Disclosure

The findings show that green strategic orientation is positively associated with subsequent carbon information disclosure, supporting H1. This result extends a literature that has largely explained carbon disclosure through climate governance, board characteristics, institutional conditions, environmental performance, and stakeholder pressure [4,8,9]. These external and governance-related factors remain important, but they do not fully explain why firms operating under similar institutional conditions disclose carbon information to different extents. The present evidence indicates that carbon transparency is also related to the degree to which environmental priorities are embedded in firms' strategic direction.

This finding complements prior research linking environmental and green strategic orientations to sustainable organizational behavior, environmental capabilities, green innovation, and long-term environmental outcomes [10–16]. Whereas these studies have mainly examined innovation and performance-related consequences, the present study shows that green strategic orientation is also associated with firms' capacity and willingness to organize and communicate carbon-related information. Carbon disclosure therefore appears to reflect not only external reporting pressure but also internal differences in managerial attention, strategic commitment, and organizational preparedness.

The economic magnitude of the relationship is meaningful. A one-standard-deviation increase in GSO is associated with an increase of approximately 4.7 percentage points in the carbon disclosure index, equivalent to about 16.5% of its sample mean. This magnitude indicates that the result is not merely a consequence of statistical power in a large sample. Its persistence in the fractional-response and one-year-ahead specifications further suggests that the association is not confined to the linear fixed-effects functional form or to disclosure measured in the same reporting period.

From a resource-based perspective, environmentally oriented managerial knowledge, organizational experience, and strategic commitment may support the development of carbon-accounting and reporting capabilities [17]. Dynamic-capabilities theory further suggests that firms with stronger environmental priorities are better positioned to recognize climate-related information needs and adjust organizational routines in response [18]. Carbon disclosure can thus be understood partly as an outcome of firms' internal capacity to interpret and respond to environmental change.

5.2. Reported Green-Transformation Intensity as a Partial Organizational Pathway

The three-wave results support H2 and H3: earlier GSO is positively associated with subsequent reported green-transformation intensity, while RGTI is positively associated with later carbon disclosure. The bootstrap analysis also identifies a statistically significant indirect association, supporting H4.

This sequence is consistent with the organizational-response perspective, according to which external environmental demands and strategic commitments influence corporate outcomes through internal interpretation and organizational processes [19]. GSO assigns strategic priority to environmental issues, whereas RGTI captures the extent to which transformation-related topics subsequently become visible in firms' organizational reporting. The results therefore provide evidence on one observable process linking environmental strategy with carbon transparency.

The interpretation of this pathway must remain consistent with the measurement of RGTI. The measure is based on transformation-related language in annual reports and therefore captures the reported salience of cleaner production, technological upgrading, energy conservation, environmental management, and related initiatives. It does not directly establish that firms have changed their production technologies, improved energy efficiency, or reduced emissions. The positive relationships between RGTI and current and subsequent green investment indicate that the textual measure contains information associated with observable environmental resource allocation. The consistent findings obtained from sentence-frequency and word-density measures further indicate that the result is not dependent on a single textual construction. Nevertheless, RGTI remains a reporting-based proxy rather than a comprehensive measure of realized organizational transformation.

The mediated share of approximately 8% is statistically significant but economically modest. This result indicates that RGTI represents one component of the GSO–CID relationship rather than its principal explanation. Most of the association appears to operate through other mechanisms, which may include board and managerial attention, stakeholder engagement, environmental expertise, internal carbon-accounting systems, reputational incentives, and direct strategic commitments to transparency. The modest mediated share therefore defines the scope of the proposed pathway rather than undermining its relevance.

The findings extend previous studies connecting environmental strategy with organizational processes, green innovation, and sustainable performance [12,15,20]. The contribution lies not in claiming that transformation-related reporting fully represents substantive corporate change, but in identifying a temporally ordered and empirically

observable pathway through which strategic environmental priorities are linked to carbon disclosure.

5.3. Reporting Propensity, Disclosure Credibility, and Greenwashing

Because GSO, RGTI, and CID are all derived partly from corporate reporting, their associations may reflect firms' broader propensity to communicate environmental information. The robustness analyses provide a qualified assessment of this concern. Controlling for annual-report length has little influence on the baseline GSO coefficient. More demanding controls for the issuance and length of separate CSR reports substantially reduce the coefficient, but the remaining association continues to be positive and statistically significant.

This attenuation suggests that reporting culture and disclosure sophistication explain an important part of the observed relationship. Firms that routinely produce extensive sustainability-related reports are more likely to communicate environmental strategy, transformation-related themes, and carbon information simultaneously. The GSO–CID association should therefore not be interpreted as completely independent of firms' general reporting behavior. Its persistence after these controls, however, indicates that reporting propensity does not provide a complete explanation.

The HardCID results offer further evidence on this issue. The positive GSO association remains when carbon disclosure is measured using more quantitative and outcome-oriented information rather than softer strategic or qualitative content. The three-wave indirect association also remains significant, although its mediated share is smaller. These findings reduce the likelihood that the results arise solely from overlapping environmental narratives.

The evidence does not establish that RGTI prevents greenwashing or that greater CID necessarily represents more credible environmental performance. Prior research shows that environmental disclosure may convey information about underlying activities but may also contain symbolic, selective, or legitimacy-oriented elements [21–24]. Standalone sustainability reports may operate as either credible signals or impression-management instruments [35], and firms may combine substantive environmental action with communication-oriented strategies [36]. The positive relationship with green investment and HardCID indicates that RGTI is not merely an arbitrary textual narrative, but the analysis cannot determine whether all reported transformation claims are fully implemented.

Carbon information disclosure should therefore be distinguished from verified environmental performance. A higher CID score indicates broader reporting coverage; it does not establish that emissions have declined, carbon efficiency has improved, or greenwashing is absent. The study contributes to the understanding of carbon transparency rather than providing direct evidence of emissions mitigation.

5.4. Pollution Exposure and the Incremental Role of Internal Strategy

The industry-based pollution analysis provides support for H5. GSO is positively associated with CID among both heavy-polluting and non-heavy-polluting firms, but the conditional association is approximately 24.8% weaker in heavy-polluting industries. The pooled interaction test confirms that the difference between the two groups is statistically significant.

This pattern is consistent with a substitution mechanism between external institutional pressure and internal strategic motivation. Heavy-polluting firms are subject to greater regulatory monitoring, creditor scrutiny, public attention, and legitimacy pressure. Carbon-market regulation, green-credit policies, environmental regulation, and green-finance initiatives have particularly important implications for the environmental investment and strategic responses of pollution-intensive firms [27–29,31,37]. Media scrutiny may further increase the visibility of their environmental activities [39]. Under these conditions, carbon

reporting may already be strongly influenced by compliance requirements and institutional expectations, leaving less incremental scope for internal GSO to shape disclosure.

The result does not imply that heavy-polluting firms disclose less carbon information. Stronger external pressure may increase their overall disclosure level. The difference concerns the marginal association between GSO and CID. Among non-heavy-polluting firms, carbon disclosure may retain a larger voluntary or discretionary component, making internal environmental strategy more influential. In heavy-polluting industries, reporting is more likely to be affected by mandatory, quasi-mandatory, or institutionally expected practices.

The firm-level carbon-intensity results, however, do not reproduce the industry-based moderating pattern. Interactions between GSO and annual mean-centered log carbon intensity, annual carbon-intensity percentiles, and carbon intensity under industry-by-year fixed effects are statistically insignificant. The estimated GSO association also remains largely unchanged across different levels of firm-level carbon intensity.

The difference between these measures is substantively informative. Heavy-polluting-industry status captures a broader institutional environment involving regulatory classification, sectoral scrutiny, financing conditions, and legitimacy expectations. Firm-level carbon intensity instead reflects the operating emissions intensity of the individual firm. Firms within the same heavily regulated industry may differ substantially in carbon intensity, while firms with similar operating intensity may face different institutional treatment across industries. The evidence therefore suggests that the moderating pattern is more closely associated with industry-level institutional exposure than with firm-level carbon intensity alone.

H5 consequently receives support under the industry-based classification, but the result should not be generalized to all measures of pollution exposure. The firm-level findings indicate that the substitution mechanism is conditional on how environmental pressure is conceptualized and measured. This distinction adds nuance to research on environmental regulation, green finance, and the behavior of heavily polluting firms [28,29,37–39].

6. Conclusions

6.1. Research Conclusions

This study examines the association between green strategic orientation and corporate carbon information disclosure and investigates the statistical indirect role of reported green-transformation intensity. The analysis uses 31,625 firm-year observations from 4845 Chinese A-share listed firms between 2016 and 2024.

The results show that lagged GSO is positively associated with subsequent carbon information disclosure, supporting H1. The association is also economically meaningful: a one-standard-deviation increase in GSO corresponds to an increase of approximately 4.7 percentage points in the disclosure index, or about 16.5% of its sample mean.

The three-wave analysis further shows that earlier GSO is positively associated with subsequent RGTI and that RGTI is positively associated with later carbon disclosure, supporting H2 and H3. The indirect association is statistically significant, supporting H4, but accounts for only approximately 8% of the total GSO–CID association. RGTI therefore represents one limited organizational pathway rather than a comprehensive explanation of the relationship.

The principal findings remain stable across alternative measurements, fractional-response estimation, reporting-propensity controls, hard carbon disclosure, and forward-looking specifications. The positive relationships between RGTI and current and subsequent green investment also indicate that the textual measure contains information related to observable environmental resource allocation.

The industry-based analysis supports H5 by showing that the GSO–CID association is weaker among heavy-polluting firms. However, this moderating pattern is not reproduced using firm-level carbon intensity. The boundary condition therefore appears to reflect the broader regulatory and legitimacy environment associated with industry classification rather than operating carbon intensity alone.

Overall, the findings indicate that corporate carbon disclosure is associated with firms' internal environmental strategic orientation and the reported salience of green transformation. Because CID measures reporting breadth rather than verified environmental performance, the results should not be interpreted as evidence that stronger GSO or more extensive disclosure necessarily reduces physical emissions.

6.2. Implications

6.2.1. Theoretical Implications

This study extends the carbon-disclosure literature by identifying green strategic orientation as an internal strategic antecedent of carbon transparency. Existing research has emphasized regulation, governance, ownership, and carbon performance; the present findings show that differences in firms' strategic environmental priorities also help explain within-firm variation in subsequent disclosure.

The study also extends research on GSO beyond green innovation and sustainable performance. Its relevance to carbon disclosure suggests that environmental strategic orientation influences not only environmental activities but also firms' capacity and willingness to organize and communicate carbon-related information.

A further contribution concerns the intermediate construct. RGTI is conceptualized as a reporting-based indicator of transformation-related organizational attention rather than as direct evidence of realized green transformation. Its statistical indirect role and its association with green investment provide evidence of one observable pathway between strategy and disclosure. The modest mediated share also shows that most of the GSO–CID association operates through other mechanisms.

Finally, the contrasting pollution-exposure results distinguish industry-level institutional pressure from firm-level operating intensity. The weaker GSO association in heavy-polluting industries is consistent with a substitution mechanism, but the absence of moderation by carbon intensity indicates that different pollution measures capture different dimensions of environmental exposure.

6.2.2. Managerial Implications

Managers should not treat carbon disclosure solely as a year-end communication exercise. More systematic carbon reporting is likely to require environmental priorities to be incorporated into strategic planning, investment appraisal, operational management, and internal information systems.

Boards and senior executives should also clarify responsibility for carbon information and strengthen coordination among environmental, production, finance, internal-control, and reporting functions. Such coordination can improve the consistency and availability of data generated across different organizational units.

Transformation-related narratives should be supported by observable commitments, including green investment, environmental-management systems, implementation targets, and quantitative carbon information. Greater alignment between strategic statements, reported activities, and measurable outcomes may improve disclosure credibility and reduce the risk of symbolic reporting.

6.2.3. Policy Implications

Policymakers and stock exchanges should improve the comparability and credibility of carbon disclosure through clearer reporting boundaries, standardized calculation methods, quantitative indicators, target-progress reporting, and independent verification.

Disclosure regulation should also distinguish reported initiatives from verified environmental outcomes. An increase in disclosure breadth should not be treated automatically as evidence of emissions reduction or improved carbon efficiency.

The industry results suggest that disclosure policy should not focus exclusively on traditionally heavy-polluting sectors. Non-heavy-polluting firms face weaker direct environmental scrutiny, making internal strategic commitment more relevant to their disclosure decisions. Proportionate guidance and capacity-building measures may therefore be needed across a broader range of listed firms.

For heavy-polluting firms, regulatory attention should extend beyond the existence of disclosure to the consistency among reported information, environmental investment, and verified operating outcomes.

6.3. Limitations and Future Research

This study is subject to several limitations. First, GSO and RGTI are derived partly from corporate reporting. Although temporal separation, report-length controls, general reporting-propensity controls, HardCID, and green-investment validation reduce common-source concerns, they cannot completely distinguish organizational substance from reporting behavior. Future research could combine textual indicators with surveys, interviews, environmental certification records, plant-level investment, or production-process data.

Second, RGTI captures the prominence of transformation-related content in annual reports rather than realized changes in production technology, energy efficiency, or emissions. Future studies could construct multidimensional transformation measures combining environmental capital expenditure, cleaner-production technologies, green patents, certification, energy-efficiency indicators, and verified emissions outcomes.

Third, CID measures the breadth of reported carbon information rather than its accuracy, credibility, or environmental effectiveness. More extensive disclosure does not necessarily imply lower emissions or the absence of greenwashing. Future research could examine external assurance, target achievement, disclosure–performance alignment, and discrepancies between environmental claims and actual emissions.

Fourth, the attrition analysis indicates that firms excluded because of unavailable lagged GSO values or missing controls differ from retained firms in several observable characteristics. Although the final sample retains approximately 89.7% of the observations available after the principal matching procedures, the findings may be less generalizable to smaller firms, firms with shorter reporting histories, and firms with incomplete governance or financial information.

Fifth, the observational design does not establish definitive causality. Firm fixed effects, temporal ordering, alternative estimators, and supplementary IV analysis strengthen the evidence, but unobserved time-varying factors may still affect the estimated associations. The peer-based instrument also relies on an exclusion restriction that cannot be directly verified. Future studies could exploit disclosure mandates, environmental-policy reforms, or other quasi-natural experiments.

Finally, the mediated share is modest, the pollution-exposure result depends on measurement, and the sample is limited to Chinese listed firms. Future research could examine alternative mechanisms, including climate governance, environmental management accounting, managerial cognition, stakeholder engagement, and internal-control quality, and could test whether the findings generalize across countries and disclosure regimes.

Author Contributions: Conceptualization, Z.M.; data curation, Z.M.; formal analysis, Z.M.; methodology, Y.W.; software, Y.W.; validation, Y.W. and W.W.; resources, W.W.; writing—original draft preparation, Z.M.; writing—review and editing, Y.W. and W.W.; supervision, Y.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The underlying data were obtained from several licensed proprietary CSMAR databases. The RGTI measures were constructed from the GSC_GreenTranWordFreqDet and GSC_GreenTranWordFreqStat tables in the China Listed Companies Green Supply Chain Research Database. The green-investment validation outcomes were obtained independently from the Listed Companies Green Environmental Investment Summary Table in the CSMAR Listed Companies Green Investment Database. The relevant original fields include expensed green investment recognized in administrative and research-and-development expenses and capitalized green investment recognized in construction in progress, fixed assets, and development expenditures. Total green investment was constructed by the authors as the sum of these components. The proprietary source data cannot be publicly redistributed. Variable-construction and estimation code is available from the corresponding author upon reasonable request, subject to the applicable CSMAR licence restrictions.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

Abbreviation	Full Form
2SLS	Two-stage least squares
CEO	Chief executive officer
CID	Carbon information disclosure
COVID-19	Coronavirus disease 2019
CRE	Correlated random effects
CSMAR	China Stock Market & Accounting Research Database
CSRC	China Securities Regulatory Commission
CSR	Corporate social responsibility
FE	Fixed effects
GEE	Generalized estimating equations
GSO	Green strategic orientation
ISO	International Organization for Standardization
IV	Instrumental variable
LM	Lagrange multiplier
PT	Particular transfer
RGTI	Reported green-transformation intensity
RMB	Renminbi
ROA	Return on assets
SD	Standard deviation
SOE	State-owned enterprise
ST	Special treatment
VIF	Variance inflation factor

Appendix A

Table A1. Attrition analysis.

Variable	Retained Sample	Missing Lagged GSO	Difference	*p*-Value	Missing Controls	Difference	*p*-Value
Firm size	22.3752	21.4363	−0.9389	<0.001	22.8564	0.4812	<0.001
State ownership	0.2946	0.0958	−0.1988	<0.001	0.6210	0.3264	<0.001
Manufacturing industry	0.6680	0.7484	0.0803	<0.001	0.5060	−0.1620	<0.001
Heavy-polluting industry	0.2090	0.1706	−0.0384	<0.001	0.2311	0.0221	0.222
Carbon information disclosure	0.2866	0.2181	−0.0686	<0.001	0.3156	0.0290	0.002
Observations	31,625	2432	—	—	913	—	—

Notes: This table compares the retained baseline sample with observations excluded because of unavailable lagged GSO values or missing control variables. Differences are calculated as the mean of the relevant excluded group minus the mean of the retained sample. The reported *p*-values are obtained from regressions of each firm characteristic on an excluded-group indicator, with standard errors clustered at the firm level. The means of state ownership, manufacturing-industry status, and heavy-polluting-industry status represent sample proportions. Pearson chi-square tests indicate that the overall CSRC industry distributions differ between the retained sample and both the missing-lagged-GSO group and the missing-controls group at the 1% level. Singleton observations are not included in the principal comparisons because they are excluded mechanically from the within-firm fixed-effects estimation.

Table A2. Detailed components and scoring rules of the carbon disclosure index.

Dimension	Indicator Symbol	Definition and Scoring Criteria	Max Score
Governance	gov_boardsupervision	1 if environmental philosophy or governance structure is disclosed; 0 otherwise	1
Governance	gov_managerespon	1 if management-level climate body is disclosed; 0 otherwise	1
Governance	gov_employeeenga	1 for employee carbon mechanisms; 1 for social green activities	2
Risk and opportunity	risk_managesystem	1 if climate risk management systems are disclosed; 0 otherwise	1
Risk and opportunity	risk_identifiassess	1 if climate-related financial or business risks are disclosed; 0 otherwise	1
Risk and opportunity	oppor_identifimanage	1 if climate-related financial or business opportunities are disclosed; 0 otherwise	1
Strategy	strategy_lctransf	1 if a low-carbon transition strategy is explicitly mentioned; 0 otherwise	1
Targets and mitigation	targets_carbonreduc	0: No disclosure; 2: qualitative targets; 4: quantitative targets	4
Targets and mitigation	targets_oclimatemanage	2 if other climate-related management goals are disclosed; 0 otherwise	2
Targets and mitigation	targets_ereducmeasures	0: No disclosure; 2: qualitative actions; 4: quantitative actions	4
Targets and mitigation	targets_btprogress	0: No disclosure; 2: qualitative business transition; 4: quantitative business transition	4
Metrics and verification	index_ggescope1	0: No disclosure; 2: qualitative Scope 1 emissions; 4: quantitative Scope 1 emissions	4
Metrics and verification	index_ggescope2	0: No disclosure; 2: qualitative Scope 2 emissions; 4: quantitative Scope 2 emissions	4
Metrics and verification	index_ggescope3	0: No disclosure; 2: qualitative Scope 3 emissions; 4: quantitative Scope 3 emissions	4
Metrics and verification	index_carbonei	0: No disclosure; 2: qualitative emission intensity; 4: quantitative emission intensity	4

Table A2. *Cont.*

Dimension	Indicator Symbol	Definition and Scoring Criteria	Max Score
Metrics and verification	index_echanges	0: No disclosure; 2: qualitative emission changes; 4: quantitative emission changes	4
Metrics and verification	index_edscope1	2 if Scope 1 emissions are decomposed by gas, region, or subsidiary; 0 otherwise	2
Metrics and verification	index_edscope2	2 if Scope 2 emissions are decomposed by region or business unit; 0 otherwise	2
Metrics and verification	index_vcinteraction	1 if value-chain climate interaction is disclosed; 0 otherwise	1
Metrics and verification	index_updowncm	1 if supply-chain climate risk management is disclosed; 0 otherwise	1
Metrics and verification	index_otherclimateinfo	1 if other climate-related indicators are disclosed; 0 otherwise	1
Metrics and verification	index_verifiability	1 if verified by ISO 14001 or third-party carbon assurance; 0 otherwise	1
Total	22 indicators	Theoretical maximum score	50

Note: This table presents the dimensions, disclosure items, and scoring criteria of the carbon information disclosure index, compiled according to the variable definitions and scoring framework provided by the CSMAR database. The original index ranges from 0 to 50, with higher scores indicating more extensive carbon-related information disclosure. For the empirical analysis, the original score is divided by 50 to obtain a standardized measure ranging from 0 to 1.

Table A3. Construction of green strategic orientation measures.

Underlying CSMAR Environmental Disclosure Item	Empirical Interpretation	Coding Rule	Included in GSO1	Included in GSO2
Environmental philosophy	Whether the firm discloses an overarching environmental philosophy or commitment	1 if disclosed; 0 otherwise	Yes	Yes
Environmental objectives	Whether the firm discloses formal environmental objectives	1 if disclosed; 0 otherwise	Yes	Yes
Environmental management system	Whether the firm reports a formal environmental-management system	1 if disclosed; 0 otherwise	Yes	Yes
ISO 14000-related certification or implementation	Whether ISO 14000-related certification or implementation is disclosed	1 if disclosed; 0 otherwise	Yes	Yes
Environmental education and training	Whether environmental education or employee training is disclosed	1 if disclosed; 0 otherwise	Yes	No
Special environmental activities	Whether special environmental campaigns or activities are disclosed	1 if disclosed; 0 otherwise	Yes	No
Environmental "Three Simultaneities" system	Whether implementation of the "Three Simultaneities" environmental system is disclosed	1 if disclosed; 0 otherwise	Yes	No
Aggregation method	Sum of included binary items	—	Sum of 7 items	Sum of 4 items
Theoretical range	—	—	0–7	0–4

Notes: GSO1 and GSO2 are constructed by the authors from seven firm-level environmental disclosure items obtained from CSMAR. The selection and grouping of the items are informed by the literature on green strategic orientation, environmental strategy, and formal environmental-management arrangements. Each item equals one when the corresponding environmental statement, system, or practice is disclosed and zero otherwise. GSO1 includes all seven items and captures the breadth of reported environmental strategic and organizational arrangements. GSO2 includes the first four items and focuses more narrowly on environmental philosophy, formal objectives, environmental-management systems, and ISO 14000-related practices. CSMAR does not provide a pre-constructed composite GSO index.

Table A4. Data sources, original fields, and construction of reported green-transformation intensity.

Component	CSMAR Source Table or Field	Database Definition and Empirical Use
Database	China Listed Companies Green Supply Chain Research Database	Licensed proprietary database distributed through CSMAR and used to obtain green-transformation-related textual-frequency data
Keyword-level detail table	GSC_GreenTranWordFreqDet	Reports keyword-level word and sentence frequencies by listed firm, reporting date, and document source
Firm-year statistical table	GSC_GreenTranWordFreqStat	Reports database-aggregated annual-report and CSR-report green-transformation frequencies and report-length measures at the firm-year level
Reporting date	EndDate	Statistical reporting date in the format YYYY-12-31; converted by the authors into the fiscal year for firm-year matching
Company identifier	InstitutionID	CSMAR listed-company identifier
Stock code	Symbol	Six-digit stock code used to match the textual data with the other firm-year datasets
Company name	ShortName	Listed-company short name, used for supplementary identification checks
Document source	Source	Equals 1 for annual reports and 2 for CSR-related reports, including CSR, ESG, environmental, and sustainability reports
Keyword field	Keywords	Green-transformation-related keyword recorded in the keyword-level detail table
Keyword word frequency	WordFrequency	Number of times the corresponding keyword appears in the report
Keyword sentence frequency	SentenceFrequency	Number of sentences containing the corresponding keyword
Annual-report total word frequency	ARGRTtlWrdFrqncy	Database-aggregated total frequency of all green-transformation keywords in the firm's annual report; used to construct the baseline RGTI measure
Annual-report total sentence frequency	ARGRTtlSntnncFrqncy	Database-aggregated total number of annual-report sentences containing green-transformation keywords; used to construct the alternative sentence-frequency measure
Annual-report total words	AnnRprtTotalWordsNum	Total number of words in the annual report; used to construct RGTI density and the annual-report-length control
Annual-report total characters	AnnRprtTotalWordCount	Total number of characters in the annual report; retained as supplementary report-length information
CSR-report total word frequency	CSRRGRTtlWrdFrqncy	Total frequency of green-transformation keywords in the CSR-related report; not used to construct the baseline annual-report RGTI measure
CSR-report total sentence frequency	CSRRGRTtlSntnncFrqncy	Total number of CSR-report sentences containing green-transformation keywords
CSR-report total words	CSRRprtTotalWordsNum	Total number of words in the CSR-related report; used in the reporting-propensity analysis
CSR-report total characters	CSRRprtTotalWordCount	Total number of characters in the CSR-related report; used as an alternative measure of CSR-report length
Baseline RGTI	Author construction based on ARGRTtlWrdFrqncy	$(RGTI_{i,t} = \ln[1 + ARGRTtlWrdFrqncy_{i,t}])$
Sentence-frequency RGTI	Author construction based on ARGRTtlSntnncFrqncy	$(RGTI_Sentence_{i,t} = \ln[1 + ARGRTtlSntnncFrqncy_{i,t}])$
Report-length-adjusted RGTI	Author construction based on ARGRTtlWrdFrqncy and AnnRprtTotalWordsNum	$(RGTI_Density_{i,t} = ARGRTtlWrdFrqncy_{i,t} / AnnRprtTotalWordsNum_{i,t} \times 10,000)$
Annual-report-length control	Author construction based on AnnRprtTotalWordsNum	$(ReportLength_{i,t} = \ln(AnnRprtTotalWordsNum_{i,t}))$
Zero-frequency observations	ARGRTtlWrdFrqncy and ARGRTtlSntnncFrqncy	Firm-year observations for which the database reports zero total frequency are retained through the logarithmic transformation
Post-download processing	Author processing	Conversion of EndDate into fiscal year, matching by stock code and year, application of logarithmic transformations, and construction of the report-length-adjusted measure

Notes: The textual-frequency data are obtained from the China Listed Companies Green Supply Chain Research Database distributed through CSMAR. The keyword-level detail table, GSC_GreenTranWordFreqDet, reports individual green-transformation keywords and their word and sentence frequencies by firm, reporting date, and document source. The firm-year statistical table, GSC_GreenTranWordFreqStat, provides database-aggregated annual-report and CSR-report frequencies and report-length fields. The baseline RGTI measure is constructed from the database-provided annual-report total word-frequency field, ARGRTtlWrdFrqncy. The alternative sentence-frequency and report-length-adjusted measures are constructed from ARGRTtlSntnncFrqncy and AnnRprtTotalWordsNum, respectively. The complete proprietary keyword dictionary and the upstream procedures used by CSMAR to tokenize reports, identify sentences, remove non-substantive report content, and construct the aggregate frequency fields are not disclosed in the database documentation. Accordingly, the study relies on the database-provided frequency fields and reports the post-download transformations performed by the authors. The green-investment outcomes used for construct validation are obtained independently from the Listed Companies Green Environmental Investment Summary Table in the CSMAR Listed Companies Green Investment Database and are not components of RGTI.

Table A5. Classification of heavy-polluting industries.

Broad Sector	CSRC Industry Code	Industry Description
Mining	B06	Coal mining and washing
Mining	B07	Petroleum and natural gas extraction
Mining	B08	Ferrous metal mining and dressing
Mining	B09	Non-ferrous metal mining and dressing
Manufacturing	C17	Textile industry
Manufacturing	C19	Leather, fur, feather and related products and footwear
Manufacturing	C22	Paper and paper products
Manufacturing	C25	Petroleum processing, coking, and nuclear fuel processing
Manufacturing	C26	Chemical raw materials and chemical products
Manufacturing	C28	Chemical fiber manufacturing
Manufacturing	C29	Rubber and plastic products
Manufacturing	C30	Non-metallic mineral products
Manufacturing	C31	Ferrous metal smelting and rolling processing
Manufacturing	C32	Non-ferrous metal smelting and rolling processing
Utilities	D44	Production and supply of electric power and heat

Note: This table presents the industry-based heavy-pollution classification used in the pollution-exposure analysis. Following Pan et al. [39], heavy-polluting industries are identified based on the Classification Management Catalogue for the Environmental Verification of Listed Companies issued by the former Ministry of Environmental Protection [43] and matched to the industry codes specified in the Guidelines for Industry Classification of Listed Companies (2012 Revision) issued by the China Securities Regulatory Commission [44]. Firms whose primary industry falls within any of the 15 listed industry codes are classified as heavy-polluting firms (Pollute = 1); all other firms are classified as non-heavy-polluting firms (Pollute = 0).

Table A6. Supplementary instrumental-variable estimates.

Variables	(1) First Stage: GSO	(2) Same-Sample FE: CID	(3) IV-2SLS: CID
Leave-one-out peer GSO	0.1669 *** (0.0345)	—	—
Lagged green strategic orientation	—	0.0271 *** (0.0009)	0.0557 ** (0.0230)
Firm-level controls	Yes	Yes	Yes
Annual-report-length control	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Observations	31,593	31,593	31,593
Number of firms	4844	4844	4844
Adjusted R^2	0.6344	0.7342	—
Within R^2	0.022	0.1129	—
First-stage excluded-instrument F	23.39	—	23.39
Kleibergen–Paap rk LM statistic	—	—	24.47
Kleibergen–Paap rk LM (p)-value	—	—	<0.001
Kleibergen–Paap rk Wald F-statistic	—	—	23.39
Anderson–Rubin test (p)-value	—	—	0.0233
Endogeneity-test statistic	—	—	1.53
Endogeneity-test (p)-value	—	—	0.2161

Notes: The instrument is the leave-one-out industry-year average of lagged green strategic orientation. Column (1) reports the first-stage fixed-effects estimate. Column (2) reports the conventional fixed-effects estimate using the common IV sample. Column (3) reports the IV-2SLS estimate. The model is exactly identified, so an overidentification test is unavailable. The IV results are interpreted cautiously because the exclusion restriction cannot be directly verified. Firm-clustered robust standard errors are reported in parentheses. **, and *** indicate statistical significance at the 5%, and 1% levels, respectively.

References

1. Ministry of Ecology and Environment of the People's Republic of China. *National Carbon Market Development Report (2024)*; Ministry of Ecology and Environment: Beijing, China, 2024. (In Chinese)
2. Shanghai Stock Exchange. *Guidelines No. 14 for the Self-Regulation of Listed Companies—Sustainability Report (Trial)*; Shanghai Stock Exchange: Shanghai, China, 2024. (In Chinese)
3. Shenzhen Stock Exchange. *Guidelines No. 17 for the Self-Regulation of Listed Companies—Sustainability Report (Trial)*; Shenzhen Stock Exchange: Shenzhen, China, 2024. (In Chinese)

4. Bui, B.; Houqe, M.N.; Zaman, M. Climate governance effects on carbon disclosure and performance. *Br. Account. Rev.* **2020**, *52*, 100880. [CrossRef]
5. Matsumura, E.M.; Prakash, R.; Vera-Muñoz, S.C. Firm-value effects of carbon emissions and carbon disclosures. *Account. Rev.* **2014**, *89*, 695–724.
6. Schaltegger, S.; Csutora, M. Carbon accounting for sustainability and management: Status quo and challenges. *J. Clean. Prod.* **2012**, *36*, 1–16. [CrossRef]
7. Tang, Q.; Luo, L. Carbon management systems and carbon mitigation. *Aust. Account. Rev.* **2014**, *24*, 84–98. [CrossRef]
8. Jaggi, B.; Allini, A.; Macchioni, R.; Zagaria, C. The factors motivating voluntary disclosure of carbon information: Evidence based on Italian listed companies. *Organ. Environ.* **2018**, *31*, 178–202.
9. Luo, L. The influence of institutional contexts on the relationship between voluntary carbon disclosure and carbon emission performance. *Account. Financ.* **2019**, *59*, 1235–1264.
10. Keszey, T. Environmental orientation, sustainable behaviour at the firm–market interface and performance. *J. Clean. Prod.* **2020**, *243*, 118524. [CrossRef]
11. Jiao, J.; Wang, C.; Yang, R. Exploring the driving orientations and driving mechanisms of environmental innovation: The case study of China Gezhouba. *J. Clean. Prod.* **2020**, *260*, 121016. [CrossRef]
12. Le, T.T. How do corporate social responsibility and green innovation transform corporate green strategy into sustainable firm performance? *J. Clean. Prod.* **2022**, *362*, 132228. [CrossRef]
13. Damert, M.; Paul, A.; Baumgartner, R.J. Exploring the determinants and long-term performance outcomes of corporate carbon strategies. *J. Clean. Prod.* **2017**, *160*, 123–138. [CrossRef]
14. Moussa, T.; Allam, A.; Elbanna, S.; Bani-Mustafa, A. Can board environmental orientation improve U.S. firms' carbon performance? The mediating role of carbon strategy. *Bus. Strategy Environ.* **2020**, *29*, 72–86.
15. Xiao, J.; Zhou, Y.; Zeng, P. How does green strategy orientation promote substantive green innovation? Evidence from Chinese manufacturing enterprises. *Econ. Change Restruct.* **2024**, *57*, 225. [CrossRef]
16. Chen, Y.-S. The driver of green innovation and green image—Green core competence. *J. Bus. Ethics* **2008**, *81*, 531–543.
17. Barney, J. Firm resources and sustained competitive advantage. *J. Manag.* **1991**, *17*, 99–120. [CrossRef]
18. Teece, D.J.; Pisano, G.; Shuen, A. Dynamic capabilities and strategic management. *Strateg. Manag. J.* **1997**, *18*, 509–533. [CrossRef]
19. Delmas, M.A.; Toffel, M.W. Organizational responses to environmental demands: Opening the black box. *Strateg. Manag. J.* **2008**, *29*, 1027–1055. [CrossRef]
20. Eccles, R.G.; Ioannou, I.; Serafeim, G. The impact of corporate sustainability on organizational processes and performance. *Manag. Sci.* **2014**, *60*, 2835–2857. [CrossRef]
21. Luo, L.; Tang, Q. Does voluntary carbon disclosure reflect underlying carbon performance? *J. Contemp. Account. Econ.* **2014**, *10*, 191–205. [CrossRef]
22. Marquis, C.; Qian, C. Corporate social responsibility reporting in China: Symbol or substance? *Organ. Sci.* **2014**, *25*, 127–148. [CrossRef]
23. Lyon, T.P.; Montgomery, A.W. The means and end of greenwash. *Organ. Environ.* **2015**, *28*, 223–249. [CrossRef]
24. Marquis, C.; Toffel, M.W.; Zhou, Y. Scrutiny, norms, and selective disclosure: A global study of greenwashing. *Organ. Sci.* **2016**, *27*, 483–504. [CrossRef]
25. Porter, M.E.; van der Linde, C. Toward a new conception of the environment–competitiveness relationship. *J. Econ. Perspect.* **1995**, *9*, 97–118. [CrossRef]
26. Ambec, S.; Cohen, M.A.; Elgie, S.; Lanoie, P. The Porter hypothesis at 20: Can environmental regulation enhance innovation and competitiveness? *Rev. Environ. Econ. Policy* **2013**, *7*, 2–22. [CrossRef]
27. Hu, Y.; Ren, S.; Wang, Y.; Chen, X. Can carbon emission trading scheme achieve energy conservation and emission reduction? Evidence from the industrial sector in China. *Energy Econ.* **2020**, *85*, 104590. [CrossRef]
28. Lu, Y.; Gao, Y.; Zhang, Y.; Wang, J. Can the green finance policy force the green transformation of high-polluting enterprises? A quasi-natural experiment based on "Green Credit Guidelines". *Energy Econ.* **2022**, *114*, 106265. [CrossRef]
29. Lin, B.; Pan, T. The impact of green credit on green transformation of heavily polluting enterprises: Reverse forcing or forward pushing? *Energy Policy* **2024**, *184*, 113901. [CrossRef]
30. Adhikari, A.; Zhou, H. Voluntary disclosure and information asymmetry: Do investors in US capital markets care about carbon emission? *Sustain. Account. Manag. Policy J.* **2022**, *13*, 195–220. [CrossRef]
31. Zhou, P.; Song, F.M.; Huang, X. Environmental regulations and firms' green innovations: Transforming pressure into incentives. *Int. Rev. Financ. Anal.* **2023**, *86*, 102504. [CrossRef]
32. Chen, W.; Zhang, L.; Shi, L.; Shao, Y.; Zhou, K. Carbon emissions trading system and investment efficiency: Evidence from China. *J. Clean. Prod.* **2022**, *358*, 131782. [CrossRef]
33. Wu, F.; Hu, Y.; Shen, M. The color of FinTech: FinTech and corporate green transformation in China. *Int. Rev. Financ. Anal.* **2024**, *94*, 103254. [CrossRef]

34. Huo, M.; Li, C.; Liu, R. Climate policy uncertainty and corporate green innovation performance: From the perspectives of organizational inertia and management internal characteristics. *Manag. Decis. Econ.* **2024**, *45*, 34–53. [CrossRef]
35. Mahoney, L.S.; Thorne, L.; Cecil, L.; LaGore, W. A research note on standalone corporate social responsibility reports: Signaling or greenwashing? *Crit. Perspect. Account.* **2013**, *24*, 350–359. [CrossRef]
36. Duan, X.; Liu, X.; Ren, X.; Tao, M. Green transformation or greenwashing? Strategic options for competitiveness in corporate green activities. *J. Environ. Manag.* **2026**, *398*, 128546. [CrossRef] [PubMed]
37. Chang, K.; Luo, D.; Dong, Y.; Xiong, C. The impact of green finance policy on green innovation performance: Evidence from Chinese heavily polluting enterprises. *J. Environ. Manag.* **2024**, *352*, 119961. [CrossRef] [PubMed]
38. Wang, C.; Wang, H.; Bai, Y.; Shan, J.; Nie, P.; Chen, Y. The impact of climate policy uncertainty on corporate pollution emissions: Evidence from China. *J. Environ. Manag.* **2024**, *363*, 121426. [CrossRef] [PubMed]
39. Pan, A.; Liu, X.; Qiu, J.; Shen, Y. Can green mergers and acquisitions under media pressure promote substantive transformation in heavily polluting enterprises? *China Ind. Econ.* **2019**, *2*, 174–192. (In Chinese)
40. Wang, H.; Liu, J.; Zhang, L. Carbon emissions and asset pricing: Evidence from Chinese listed companies. *China J. Econ.* **2022**, *9*, 28–75. (In Chinese) [CrossRef]
41. He, Y.; Tang, Q.; Wang, K. Carbon performance and financial performance. *Account. Res.* **2017**, *2*, 76–82. (In Chinese)
42. *ISO 14001:2015*; Environmental Management Systems—Requirements with Guidance for Use. International Organization for Standardization (ISO): Geneva, Switzerland, 2015.
43. Ministry of Environmental Protection of the People's Republic of China. *Notice on Issuing the Classification Management Catalogue for the Environmental Verification of Listed Companies*; Huanbanhan [2008] No. 373; Ministry of Environmental Protection: Beijing, China, 2008. (In Chinese)
44. China Securities Regulatory Commission. *Guidelines for Industry Classification of Listed Companies (2012 Revision)*; CSRC Announcement [2012] No. 31; China Securities Regulatory Commission: Beijing, China, 2012. (In Chinese)