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The Effect of Carbon Disclosure Quality on Green Bond Financing Cost

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ABSTRACT

Existing research on financing costs primarily focuses on traditional financial factors, such as credit ratings, and offers limited examination of non-financial information. This study examines the impact of the quality of carbon information disclosure on financing costs using a fixed-effects panel regression, based on data from 166 Chinese listed companies that issued green bonds from 2014 to 2024. Results show a significant negative relationship: Better disclosure reduces bond costs. As carbon disclosure reflects a company's environmental and governance commitment, it influences investors' perceptions and risk assessments, thereby affecting financing costs. The study also finds that companies in carbon-intensive industries are more sensitive to changes in carbon intensity. China's initiatives to reduce carbon emissions and support green bonds have heightened the importance of carbon disclosure for financing costs. This study provides novel insights into how carbon information disclosure affects green financing in China, enabling regulators to refine their policies and guiding companies towards low-carbon strategies.

1 | Introduction

Green bonds, an important financial tool for channelling capital into green projects, have grown rapidly worldwide since 2013 (Flammer 2021). According to the Climate Bond Initiative, global green bond issuance totalled \$671 billion in 2024, setting a new market record (Climate Bond Initiative 2024). However, as the global green bond market continues to expand, the gap between policy frameworks and market development has become more apparent. Companies are increasingly utilising green financing tools to support their green transitions and emissions-reduction efforts, aligning with the broader goal of achieving carbon neutrality. Nonetheless, relevant policy frameworks have yet to establish a unified, mature institutional structure for disclosure standards, pricing mechanisms and regulatory coordination (Bhutta et al. 2022). In the realm of green finance, this suggests a potential disparity between corporate green actions and policy guidance. This asymmetry undermines the effectiveness of resource allocation in green finance, a problem further exacerbated by market uncertainty. This issue is particularly

pronounced in the ambiguity and lack of oversight surrounding green bond financing mechanisms.

The unwelcome possibility of greenwashing has become a significant issue in green finance practices. Greenwashing involves falsely claiming that green bond funds are used for environmental projects or exaggerating environmental commitments without implementing meaningful measures to achieve environmental benefits (X. Shi et al. 2023). As the influence of greenwashing grows, investors increasingly rely on impartial verification of the validity of green bond environmental certifications before making investment decisions. To mitigate potential legal and reputational risks, advocates for green projects must also ensure sufficient disclosure of information (Climate Bond Initiative 2024). Therefore, enhancing transparency in green bond markets has become a central issue.

Carbon information disclosure (CID) is widely regarded as a valuable tool to mitigate information asymmetry between green bond issuers and investors due to its measurable

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features. According to signalling theory, businesses can directly provide investors with information on their carbon emissions to demonstrate their genuine commitment to environmental sustainability (Guenther et al. 2016; L. Luo and Tang 2014). This practice has been shown to alleviate investors' concerns about greenwashing risks and facilitate access to lower financing costs (Rehman et al. 2023). Recent research suggests that the strict disclosure of environmental information, based on accurate and objective data, especially through third-party certification, likely improves signal transmission and boosts green premiums (Clarkson et al. 2008; Fatica et al. 2021). Therefore, documenting carbon emissions information for green bonds helps uphold market participants' confidence in green projects and supports regulatory authorities in managing financing projects that genuinely meet green standards. This, in turn, makes it much easier to effectively attract green financial resources.

Given its position as one of many nations experiencing rapid growth in green finance and as the nation with the strongest policy support worldwide, China's green bond market is of particular interest. Green bonds have gradually shifted from a marginal financing tool to a crucial component of green financial systems, following the issuance of green bond guidelines by the People's Bank of China and the National Development and Reform Commission in late 2015 to test the market (Wang and Zhang 2017). This development can be attributed to the national government's focus on green development and the introduction of relevant policies and regulations. Currently, China's annual green bond issuance stands at \$68.9 billion, accounting for 10% of the global total and ranking third worldwide (Climate Bond Initiative 2024). Despite ongoing growth in market size, significant institutional differences and implementation gaps between China and international standards, particularly in information disclosure and regional regulatory coordination, have hindered the development of market transparency and trust. When the effectiveness of green projects is difficult to evaluate directly, variations in the quality of carbon disclosure have become a key factor influencing investors' risk perceptions and financing costs. Considering the structural characteristics of China's green bond market, including but not limited to strong government dominance, regional regulatory divergence and the nascent state of the disclosure mechanism, it can be concluded that the quality of CID has a greater impact on bond pricing (Lin and Hong 2022). Therefore, China presents an ideal context for exploring whether the quality of CID can serve as an effective market signal in conditions of institutional uncertainty.

The topic of green bonds has attracted considerable attention from the academic community, with numerous studies conducted on the subject. Existing literature primarily focuses on the motivations behind issuing green bonds (Flammer 2021; Bedendo et al. 2023; Dutordoir et al. 2024), the factors influencing the pricing of green bonds (Fatica et al. 2021; Agliardi and Agliardi 2021) and the economic and environmental effects of green bond issuance (Tang and Zhang 2020; ElBannan and Löffler 2024; Benlemlih et al. 2023). However, the role of CID quality in the green bond issuance process has not been sufficiently examined. Furthermore, Rehman et al. (2023) have examined information asymmetry and signal transmission

mechanisms in the context of green finance, noting that environmental information disclosure can influence investors' pricing judgements and risk perceptions of green instruments to some extent. There remains a lack of systematic empirical research on whether differences in CID quality significantly affect green bond financing, particularly regarding how to reduce 'greenwashing' risks and optimise risk pricing mechanisms. In response, this study uses a fixed-effects panel regression with data on 166 Chinese listed companies that issued green bonds between 2014 and 2024 to examine the impact of CID quality on financing costs. The findings show a significant negative relationship: Better disclosure reduces bond costs. As carbon disclosure reflects a company's environmental governance and commitment, it shapes investor perceptions of risk and, in turn, financing costs. We also find that companies in carbon-intensive industries are more sensitive to changes in carbon intensity.

The rest of the paper is structured as follows. Section 2 critically reviews the literature on green bonds, financing costs and carbon disclosure and then proposes the hypothesis. Section 3 presents the methodology, followed by the findings in Section 4. The final section outlines the contribution to the literature and the practical implications.

2 | Background Literature and Hypothesis Development

2.1 | Green Bonds and Financing Costs

The emergence of green bonds has been identified as a potential solution to the financing constraints faced by green projects, with the aim of facilitating the transition of the economy towards a green, low-carbon model (Flammer 2021). The genesis of green bond markets can be traced back to 2007, when the European Investment Bank pioneered the inaugural issuance of 'climate awareness bonds' (Jankovic et al. 2022). Since then, the market has experienced substantial expansion in its geographic reach, the diversity of its financial instruments and the range of its issuers. This growth has led to the formation of a multi-faceted structure, with governments, development finance institutions and corporations emerging as the primary participants (Tang and Zhang 2020). However, the rapid expansion of green bond markets has been accompanied by widespread concerns about greenwashing, in which companies exaggerate their sustainability efforts to mislead investors, prompting some to question the credibility of the green label (Benlemlih et al. 2023). This phenomenon has prompted academic scrutiny of a central economic issue: whether green bonds genuinely offer the benefit of stable financing costs.

Although the regulatory system and policy framework supporting green markets are gradually improving, a lack of unified, authoritative consensus persists on key institutional issues, such as the definition of green bonds, criteria for their determination and the taxonomy of green projects. In 2014, the International Capital Markets Association proposed a definition of a green bond as a debt instrument whose proceeds, or equivalent amounts, must be exclusively used to support green projects with clear environmental benefits. These projects may include

environmentally or climate-friendly initiatives such as renewable energy, energy efficiency improvements, pollution control and climate change adaptation (Jin et al. 2020). The classification established by the Climate Bonds Initiative defines specific eligibility criteria and industry-sector green taxonomies, which are provided to third-party certification bodies to qualify green bonds. Design considerations such as green label certification, earmarking of collected funds and environmental information disclosure are common in these guidelines. These measures can improve transparency and ensure the proper use of funds by addressing uncertainty and information asymmetry associated with green project financing. Investors receive market signals about a bond's environmental quality through mechanisms such as green labels, third-party verification, environmental information disclosure and other features. This, in turn, enhances investors' confidence in the issuer's ability to allocate funds to green projects, boosting acceptance of the green label and investors' willingness to accept lower returns in support of environmentally friendly investments. Consequently, this strategy reduces the cost of financing green bonds (Z. Li et al. 2020; Fatica et al. 2021).

2.2 | Determinants of Green Bond Financing Costs

The financing costs of green bonds are shaped by a blend of traditional and non-traditional factors through market mechanisms. In some studies, the yield spread of green bonds has been shaped by traditional factors, such as credit ratings, maturity and issuer type (Barua and Chiesa 2019). For example, Nanayakkara and Colombage (2019) found that issuers with higher credit ratings generally issue green bonds at lower yields, consistent with standard bond pricing principles. Green bonds, however, introduce non-financial variables such as environmental characteristics, market preferences, certification systems and disclosure mechanisms due to their specific purpose and additional institutional arrangements. These variables affect their final financing costs through mechanisms such as investor signalling or reduced information asymmetry (Ehlers and Packer 2017). According to Z. Li et al. (2020), CSR and green certifications play a significant role in the issuance of green bonds, with higher CSR scores associated with lower bond yields.

An extensive body of literature has examined whether green bonds typically command lower interest rates due to non-financial information mechanisms embedded in their institutional design. In other words, the presence of such mechanisms might give rise to a so-called 'greenium'. The 'greenium' refers to the ability of issuers to raise funds at a lower cost. This, in turn, increases the financial availability and economic appeal of green projects (Zerbib 2019). Some studies provide evidence that green bonds exhibit a significant yield decline relative to conventional bonds (Dorfleitner et al. 2022). However, it has also been established that the issuance costs of green bonds are marginally higher than those of conventional bonds. The extent of any premium depends on conditional variables, including the level of certification, the frequency of issuance and the intensity of disclosure (Flammer 2021). Consequently, the cost of green bond financing is influenced not only by traditional risk premium factors but also by non-financial variables such as environmental information and signal credibility.

2.3 | CID and Green Bond Financing

Among non-financial indicators, the role of information disclosure in green bond pricing has attracted growing attention, and the importance of CID quality in shaping green bond financing costs has become increasingly evident. Carbon disclosure can be defined as the extent to which companies report their carbon emissions, emission-reduction strategies and climate-related risks in accordance with regulatory requirements (Rehman et al. 2023; Alsaifi et al. 2020). Previous literature has examined the significance of disclosure quality for equity financing costs (Albarrak et al. 2019). By constructing a voluntary disclosure index, Botosan (1997) found a negative correlation between corporate disclosure levels and equity capital costs. Building on this, Rehman et al. (2023) further confirmed that companies with higher levels of voluntary disclosure have lower capital costs. These findings suggest that high-quality carbon disclosure signals demonstrate corporate commitment to environmental responsibility and reinforce investors' trust in environmental issues, thereby contributing to the formation of a positive green premium effect.

Several studies have examined the link between carbon disclosure and debt costs (W. Luo et al. 2019). Using data from the United States, Sengupta (1998) reports a significant negative relationship between the quality of corporate disclosure and debt costs. Additionally, Ding et al. (2022) examined Chinese listed manufacturing companies from 2014 to 2016 and found that higher levels of CID were associated with lower debt financing costs. This finding aligns with Hu and Liang (2024), who observed that in regions characterised by weak environmental regulation, limited public environmental awareness and restricted market competition, the debt-cost-reducing effect of CID is more pronounced.

Although existing studies largely agree that disclosure provides several benefits, the current literature still has significant gaps. Firstly, many studies focus on broad concepts such as 'green information' or 'environmental disclosure' without providing detailed differentiation or quantitative assessment of specific categories, such as 'carbon information' (e.g., W. Luo et al. 2019). Most previous studies examined disclosures as a whole, failing to account for differences in CID quality. This distinction is important because high-quality disclosures, marked by credibility, specificity and verifiability, are more effective at reducing greenwashing and increasing investor trust, which in turn has a greater impact on bond pricing. Secondly, most research focuses on the corporate level and rarely examines how the quality of carbon disclosure affects green bond financing costs (e.g., Flammer et al. 2021; Karim et al. 2021). Thirdly, the literature primarily focuses on European and American markets (e.g., Sengupta 1998) and lacks a localised explanation of carbon disclosure and bond pricing mechanisms in the Chinese institutional context. In China, progress in carbon disclosure remains in its early stages, marked by inconsistent standards and imperfect regulation. Empirical evidence directly linking CID quality to green bond financing costs is scarce, especially in emerging markets. In China, the institutional environment, characterised by weaker investor protections, changing disclosure standards and substantial government involvement, may increase

the extent to which high-quality carbon information influences pricing. This study highlights a new mechanism: Rather than simply whether disclosure exists, focusing on CID quality reveals how environmental transparency affects green bond prices across both state-owned and private companies. These institutional characteristics could heighten the influence of disclosure quality on market responses (J. Shi 2022). Given China's dual role as both a major driver of growth and a significant emitter of carbon, it is important to consider its participation in the green bond market. Therefore, exploring how the quality of CID affects green bond financing costs and elucidating its transmission mechanisms in China can enrich the global green finance literature and offer valuable policy insights.

2.4 | Hypothesis Development

Signalling theory offers a valuable framework for examining carbon disclosure (e.g., L. Luo and Tang 2014). From this perspective, a firm's actions and choices serve as signals to the market about its underlying value and future potential (e.g., L. Luo and Tang 2014). These signals can strengthen investor trust among those concerned with ESG factors, encouraging effective engagement (Bhutta et al. 2022). This positive signal has been shown to give companies a competitive edge in the green bond market. Specifically, when a bond issuer clearly discloses the company's carbon emissions, it signals a commitment to sustainable development and the capacity to fulfil environmental responsibilities. This, in turn, helps create a positive green image and boosts investor confidence (Hu and Liang 2024). Biddle et al. (2009) demonstrated that disclosing carbon emissions when they are due also acts as a reinforcing signal. High levels of detail, verifiability and timeliness in disclosures are likely to enhance the issuer's credibility in the eyes of investors. This signals high standards of transparency in managing green projects and a strong level of accountability in environmental governance. Research has shown that high-quality disclosure entities are more likely to be perceived by investors as having a lower risk of default (Martin and Moser 2016). Additionally, their green bonds are more likely to carry a lower risk premium than those with lower quality disclosures, resulting in lower financing costs. In the context of the green bond market, given the long-term, non-financial nature of green projects, investors rely heavily on non-financial data, including carbon information, to assess environmental performance and the effectiveness of fund utilisation (Taghizadeh-Hesary and Yoshino 2020). Therefore, when a green bond issuer provides a well-structured, detailed and frequently updated carbon disclosure report covering key elements such as carbon emissions data, emission-reduction targets, environmental governance structure and green project utilisation, investors are likely to interpret this as a positive indicator. This could lead to a lower perceived risk of such bonds, thereby reducing the cost of financing green bonds.

The financing process for green bonds is primarily shaped by information asymmetry between creditors and issuers. Compared with traditional bonds, green bonds are a relatively new financial instrument with a brief history, underdeveloped market mechanisms and a standards system that is currently being refined (Bhutta et al. 2022; Flammer 2021). This institutional

and market immaturity means that information about environmental attributes, project compliance and efficient use of capital may be incomplete or unclear during transmission. This is particularly challenging for investors, given the characteristics of green bonds, such as longer maturities and slower realisation of environmental benefits (Teti et al. 2022). As a result, investors often fail to fully assess the true green value and risks. This raises doubts about the project's viability and its potential returns. In situations where information is limited, investors tend to adopt a risk-averse approach, demanding higher risk premiums to offset uncertainties and potential losses (Easley and O'Hara 2004). This directly increases the financing costs for green bond issuers and diminishes their enthusiasm for using green bonds as a tool for low-carbon transition. However, the introduction and development of the CID mechanism have helped resolve concerns about information asymmetry. By consistently concealing information on corporate environmental management, carbon emissions, green project funding and performance evaluation, CID hampers transparency and auditability in green projects, thereby providing investors with less reliable data (Alsaifi et al. 2020; Clarkson et al. 2008). Within the green bond market, it is also crucial to recognise that the environmental information disclosure mechanism serves as an essential bridge of information and a trust-building tool. This nearly reduces potential risks for enterprises and encourages a wider range of investors to participate in green bonds, leading to lower financing costs (Benlemlih et al. 2018). Accordingly, this study proposes the following hypothesis:

Hypothesis 1. *The quality of CID during the issuance periods of green bonds is negatively correlated with their yield spreads.*

3 | Methodology

3.1 | Data Source and Data Selection

The People's Bank of China published the China Green Bond Endorsed Project Catalogue in 2015, marking the country's first official regulatory document. The classification system under review divides green bond investment projects into six major categories and 31 subcategories. In 2021, the classification was updated, adding six major categories and 25 subcategories. The Green Bond Issuing Guidelines issued by the National Development and Reform Commission of China specify that green bonds are corporate bonds; therefore, all funds raised are allocated to 12 key projects that support green cycles and low-carbon development. Similarly, the National Association of Financial Market Institutional Investors issued the Guidelines on Ongoing Information Disclosure During the Life of Green Bonds, which outline the fundamental disclosure requirements for green bonds during their lifespan, including how to raise funds, where to allocate the funds, where to report carbon emissions data and other relevant information. These documents define the specific categories of 'green' projects, standardise the use of bond proceeds, establish green certification mechanisms and outline third-party verification processes.

The issuance data on green bonds in this study were obtained from the Bloomberg and Wind databases. Since the end of 2015, China's green bond market has gradually established a

multi-departmental, coordinated regulatory framework. Across all databases, bonds that meet the green standards set by regulatory authorities (including the PBoC, the NDRC, the China Securities Regulatory Commission and the National Association of Financial Market Institutional Investors) are labelled green (Lin and Hong 2022). It is evident that all green bonds selected in this study meet this standard.

The selection of Chinese green bonds in this study is guided by specific criteria. Firstly, since China first issued green bonds in 2014, the study selected green bonds issued in China from 2014 to 2024 as the sample. Data on these green bond issuances were obtained from the Wind database, and the sample constitutes an unbalanced panel dataset. To ensure the availability of both carbon disclosure scoring data and financial data related to the bond issuers, the focus was on Chinese A-share listed companies. The sample includes corporate bonds, enterprise bonds, financial bonds, medium-term notes, short-term financing bills and asset-backed securities. Data samples were then subjected to exclusion, removing floating rate bonds, bonds denominated in currencies other than the Chinese Yuan and subordinated bonds. The financial and carbon information data were matched, and samples with missing core data were excluded. After processing, the final dataset comprises non-balanced panel data from 166 companies over a 10-year period, totalling 523 bond observations. Of these, 383 green bonds were issued in the interbank market, and 140 were listed on the Shenzhen Stock Exchange and Shanghai Stock Exchange. The financial performance of green bond issuers in China, government bond yields and carbon disclosure quality metrics were obtained from Bloomberg. The analysis was conducted using Stata version 18.0.

3.2 | Variable Selection

3.2.1 | Dependent Variable

The dependent variable is the cost of green bond financing. The research adopts the approach used in many related studies and utilises yield spreads in the primary market as an indicator of the green bond financing costs (Z. Li et al. 2020; Meng and Yin 2019). This study calculates the yield spread of green bonds by taking the difference between the yield to maturity of government bonds issued in the same period and with similar maturities and the coupon rate of green bonds. This approach is much better at accurately visualising the impact of green bond financing costs.

3.2.2 | Independent Variable

The E score from ESG ratings serves as a proxy measure of the quality of CID in this study (Karim et al. 2021). There are several reasons why this study concentrates solely on the E dimension. Firstly, its assessment includes greenhouse gas emissions, energy conservation and emission-reduction policies, carbon management mechanisms and the disclosure of environmental targets. These elements closely align with the core content of CID. Secondly, E scores provide a more comprehensive and direct reflection of corporate environmental transparency and emission-related practices than single carbon emission

indicators and multiple ESG environmental indicators, helping to better capture differences in the quality of information disclosure (Fliegel 2025). Lastly, W. Li et al. (2024) discovered that the E score had a greater impact on bond financing costs than the other two dimensions of ESG, specifically the Social (S) score and the Governance (G) score. The E score ranges from 0 to 10, with higher scores indicating better, more standardised management practices and disclosure in the environmental dimension. Referring to previous literature, we controlled for bond-level characteristics, including maturity and issue amount (Z. Li et al. 2020; Fatica et al. 2021). We also controlled for issuer-level characteristics, including company size, tangible asset ratio, return on assets and industry, all of which are listed in Table 1.

3.3 | Model Design

This study adopts a combination of quantitative research and empirical testing as its methodological approach. The subsequent steps involve collecting data, establishing a model and analysing the data to test whether the hypothesis is valid. Due to the obvious unbalanced structure of the sample, this study follows the practice commonly adopted in relevant empirical studies on green finance and directly uses fixed-effects panel regression for estimation (Flammer 2021; ElBannan and Löffler 2024). Using a firm-level fixed-effects panel approach is suitable because it accounts for unobserved, time-invariant factors, such as managerial quality, corporate culture or baseline environmental preferences, that could simultaneously affect disclosure quality and financing costs (e.g., Sengupta 1998). Considering that the vintage level may be affected by fluctuations in macroeconomic policies, international market conditions and related factors, the use of fixed time effects (θ_{it}) in the analysis is employed. The model also incorporates firm-clustered robust standard errors. This methodological approach enables the identification of causal relationships between the core variables while controlling for these potential disturbances, thereby improving the internal validity of the estimates. The regression model constructed in this research is shown below:

$$\text{Spread}_{it} = \beta_0 + \beta_1 \text{CIDQ}_{it} + \beta_2 \text{CIDQ}_{it} * \text{Sector}_{it} + \gamma_1 \text{SIZE}_{it} + \gamma_3 \text{Tangibility}_{it} + \gamma_4 \text{ROA}_{it} + \gamma_5 \text{Amount}_{it} + \gamma_6 \text{Tenor}_{it} + \theta_{it} + \epsilon_{it}$$

TABLE 1 | Variable description.

| Variable | Description |
|-------------|--|
| Spread | Yield spread, the difference between the coupon rate of green bonds when they are issued and the yield on government bonds that have the same maturity |
| CIDQ | CID quality of green bonds |
| Tenor | Maturity of green bonds in years |
| Amount | Green bond issuance amount |
| Size | Natural logarithm of issuers' total assets |
| ROA | Return on assets of companies |
| Tangibility | Ratio of tangible assets of companies |

where $Spread_{it}$ refers to the yield spread of green bond i ; $CIDQ$ refers to the CID quality at the time of green bond issuance; and the remaining variables are control variables. Additionally, industry-score interaction fixed effects are also included, namely, $CIDQ_{it} * Sector_{it}$, to further capture the possible moderating effect of industry system differences on the mechanisms affecting carbon disclosure, with a view to enhancing the robustness of the results. ϵ_{it} is the error term.

4 | Findings

4.1 | Sample Description

As shown in Figure 1, the distribution of annual green bond issues is analysed, focusing on the period from 2014 to 2024. The figure clearly indicates a significant increase in green bond issuance since 2014, with a projected peak in 2022. This trend illustrates that the policy environment of the green bond market,

combined with the market's strong demand for financing green projects, will significantly influence the development of green bonds (Taghizadeh-Hesary and Yoshino 2020).

Meanwhile, issuers of green bonds come from a broad range of industries. As shown in Figure 2, most green bond issuers are focused on resource-intensive utility sectors, such as Energy & Water Supply, with the second-largest group in the Manufacturing sector. This is due to China's policy to reach peak carbon emissions by 2030 and achieve carbon neutrality by 2060, which mainly targets green bond-funded projects on clean energy and infrastructure upgrades. The support from green bonds has proven to help develop renewable energy, ease the pressure on transforming traditional industries and promote green technological innovation and process improvements within these sectors (Escalante et al. 2020).

Moreover, there has been an increase in the issuance of green bonds among financial institutions. Bedendo et al. (2023)

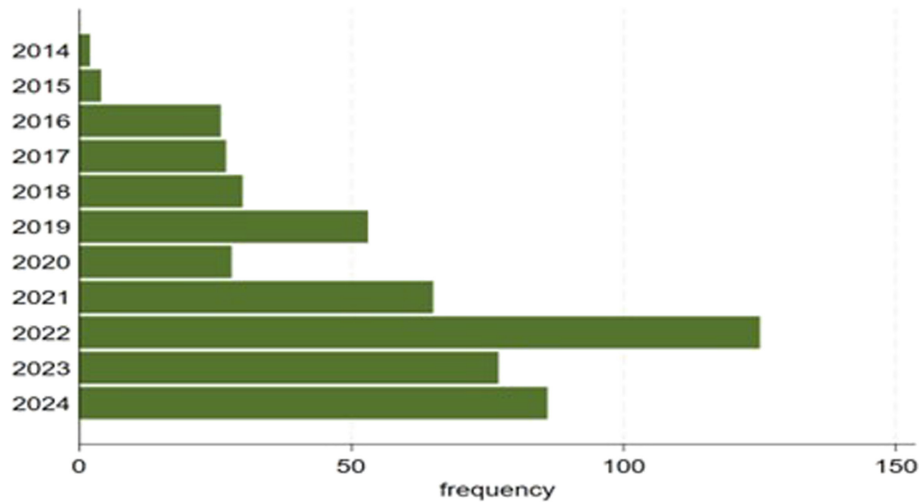


FIGURE 1 | Annual distribution of green bond issuance.

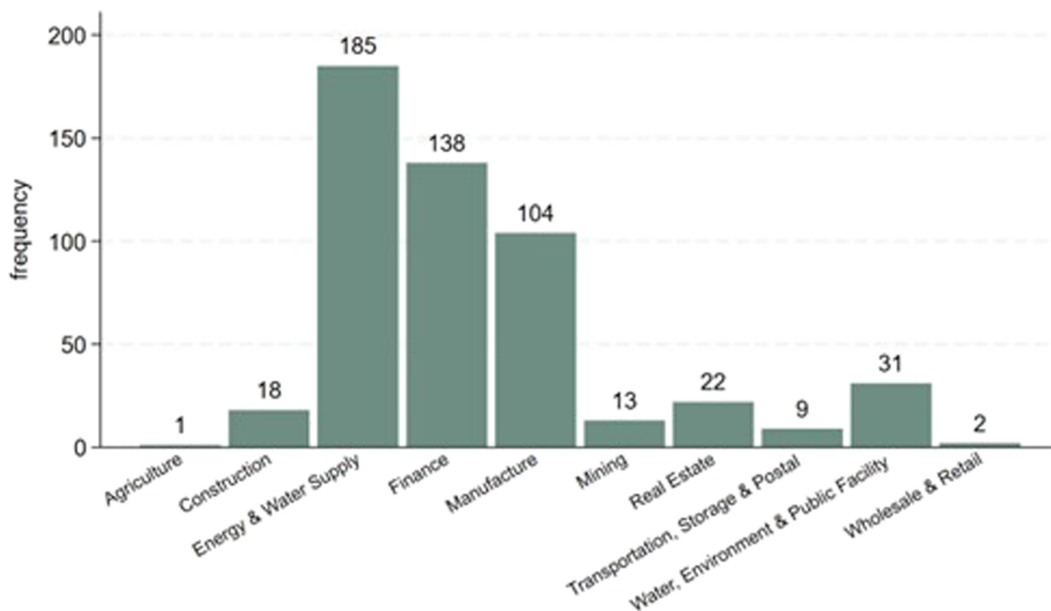


FIGURE 2 | Sectoral distribution of green bond issuers.

emphasise that financial institutions are increasingly focusing on carbon disclosure and responding to the demand from green investors for low-carbon assets by offering green loans and sustainable financing products. Simultaneously, these institutions strengthen their competitive position in the green finance market through issuing green bonds and gradually reducing credit support for highly polluting enterprises in their asset allocation, thereby attracting many investors to green investments (Fatica et al. 2021). Consequently, financial institutions are the primary supporters of green bonds, underscoring the capacity and resource allocation potential of the financial system in the decarbonisation process (Taghizadeh-Hesary et al. 2021). The sectoral distribution of the sample demonstrates the strong connection between the demand for green financing and the carbon emission characteristics of each sector.

As demonstrated in Figure 3, the carbon disclosure quality score exhibits a bimodal distribution pattern, with notable concentrations between 3 and 4 and 6 and 8, indicating a clear stratification trend in corporate carbon disclosure practices. This stratification may stem from the heterogeneity of carbon emission intensity across industries, differences in companies' attitudes towards ESG policy responses and varying expectations regarding the economic benefits of disclosing carbon information (Alsaifi et al. 2020). On the one hand, companies with high scores are primarily large

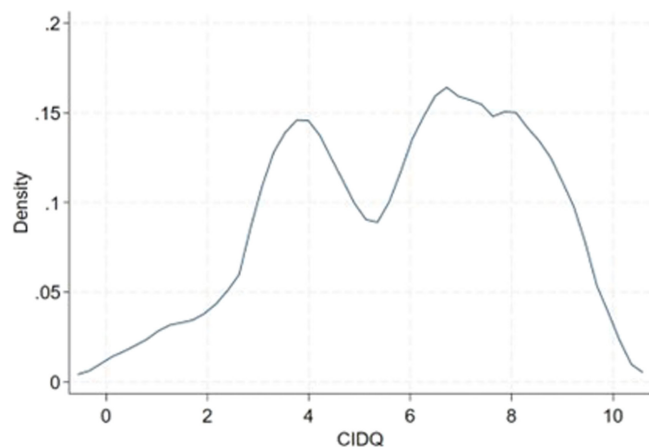


FIGURE 3 | Carbon information disclosure quality (CIDQ) distribution.

TABLE 2 | Descriptive statistics.

| Variables | Mean | P50 | Std.Dev | Min | P25 | P75 | Max |
|-----------|-------|-------|---------|--------|-------|--------|--------|
| Spread | 93.08 | 63.80 | 89.64 | -81.00 | 33.70 | 117.00 | 505.90 |
| CIDQ | 5.87 | 6.29 | 2.29 | 0.03 | 3.95 | 7.71 | 10.00 |
| ROA | 0.03 | 0.02 | 0.03 | -0.14 | 0.01 | 0.44 | 0.28 |
| lmc | 5.40 | 5.16 | 2.02 | 1.24 | 4.06 | 6.22 | 10.80 |
| tar | 0.34 | 0.38 | 0.27 | 0.00 | 0.01 | 0.60 | 0.83 |
| IA | 2.64 | 1.00 | 5.26 | 0.04 | 0.50 | 2.00 | 30.00 |
| Tenor | 3.13 | 3.00 | 2.43 | 0.03 | 2.16 | 3.00 | 20.01 |

Note: $N = 523$.

firms or those with high ESG standards, often equipped with mature environmental management systems. Conversely, companies with lower scores may lack the resources or governance structures necessary to disclose carbon information effectively.

4.2 | Descriptive Statistics

To gain a deeper understanding of the fundamental characteristics and distribution trends of the sample data, Table 2 presents the descriptive statistical results for all variables. Regarding the dependent variable, the mean value of the green bond credit spread (Spread) is 93.08 basis points, with a standard deviation of 89.64, indicating significant differences in financing costs among green bonds issued by different companies. The lowest value in the sample is negative (-81), suggesting that the market highly values certain green bonds and may even price them at a premium. For the independent variables, the mean value of carbon disclosure quality (CIDQ) is 5.87 (out of 10), indicating that the overall level of environmental information disclosure and environmental governance performance of the sample companies is relatively moderate. The minimum value of the disclosure score is 0.03, and the maximum value is 10, indicating that the distribution of corporate carbon disclosure spans both high- and low-scoring companies, which is conducive to a comprehensive examination of the relationship between the quality of carbon disclosure and the cost of green bond financing.

Meanwhile, at the company level, the return on total assets has a mean value of 3% and a standard deviation of 0.03, indicating that the overall profitability of the sample companies is relatively balanced. The negative values of some of these companies may be attributed to operating losses in a given year or to being in the early stages of green transformation and not yet realising the release of economic benefits. The mean (5.40) and standard deviation (2.02) of firm size (lmc) indicate that the sample firms are relatively concentrated in terms of market capitalisation size distribution. The mean tangible assets ratio (tar) is 34.48%, suggesting that the majority of companies are grounded in physical assets and possess a robust asset structure. From the bond perspective, the quartile range of the tenor of the bonds (Tenor) is centred between 2.16 and 3, indicating that China's green bond market is still dominated by short- and medium-term financing. The mean value of bond issue size (IA) is 2.64 billion yuan, with a maximum value

TABLE 3 | Pearson correlation coefficient matrix between variables.

| | Spread | CIDQ | ROA | Size | Amount | Tenor | Tangibility |
|-------------|-----------|----------|-----------|-----------|-----------|--------|-------------|
| Spread | 1 | | | | | | |
| CIDQ | -0.158*** | 1 | | | | | |
| ROA | 0.016 | 0.020 | 1 | | | | |
| Size | -0.380*** | 0.444*** | -0.288*** | 1 | | | |
| Amount | -0.203*** | 0.316*** | -0.197*** | 0.627*** | 1 | | |
| Tenor | 0.104** | 0.002 | -0.142*** | -0.015 | 0.061 | 1 | |
| Tangibility | -0.052 | -0.099** | 0.250*** | -0.387*** | -0.390*** | -0.054 | 1 |

Note: This table reports the correlation between pairs of all variables.

** $p < 0.05$.

*** $p < 0.01$.

of 3 billion yuan, indicating a significant difference in capital needs between enterprises in green financing. In summary, the variables exhibit significant differences in their statistical distributions, thus providing a solid data foundation for further empirical analysis in this research.

4.3 | Variable Correlation and Multicollinearity Test

Before performing the regression analysis, the study carefully examined the relationship between the main variables and the risk of multicollinearity issues. This was done using Pearson's correlation coefficient matrix and the variance inflation factor (VIF) test, aiming to ensure the robustness and validity of the subsequent regression model estimates.

The Pearson correlation coefficient matrix between the main variables is presented in Table 3. The findings indicate a substantial negative correlation between the carbon disclosure score and the green bond financing cost (Spread) (coefficient = -0.158 , $p < 0.001$), which provides preliminary verification of Research Hypothesis 1 that 'the higher the quality of carbon disclosure, the lower the corporate financing spread'. However, it is essential to note that correlation analysis alone is insufficient to establish a causal relationship between the two, and further testing through regression analysis is necessary. With the exception of the carbon disclosure score, the cost of green bond financing has been found to be negatively correlated with the market size (Size), the bond issue size (Amount) and the tangible asset ratio (Tangibility). Furthermore, at the 0.05 confidence level, a significant correlation exists between the cost of green bond financing and bond maturity ($r = 0.104^{**}$, $p < 0.05$), suggesting that as bond maturity lengthens, the required financing cost increases. Concurrently, it is imperative to exercise caution with regard to the presence of partial significant correlations between control variables, such as Size with Amount (0.627^{***}) and with CIDQ (0.444^{***}) and ROA with Size (-0.288^{***}), which necessitate further evaluation in conjunction with the VIF value.

To further validate the stability of the regression model, Table 4 presents the results of the VIF test. As posited by O'Brien (2007) in their review, a VIF exceeding 10 is typically regarded as a

TABLE 4 | Variance inflation factor (VIF).

| Variable | VIF | 1/VIF |
|-------------|------|-------|
| Size | 2.08 | 0.481 |
| Amount | 1.74 | 0.575 |
| CIDQ | 1.3 | 0.771 |
| Tangibility | 1.27 | 0.790 |
| ROA | 1.17 | 0.852 |
| Tenor | 1.03 | 0.967 |
| Mean VIF | 1.43 | |

criterion for identifying severe covariance in empirical judgement. The VIF values of all variables in the sample are below the conventionally set critical value of 10 (and even below the more stringent 5), with an average VIF value of 1.43. This indicates that the model does not suffer from the problem of severe covariance and that the selected variables are appropriate and do not bias the estimation results.

In summary, the correlation analysis and covariance diagnosis in this section provided preliminary verification of the reasonable structural relationship between the variables and elimination of the potential risk of bias in the estimation model due to the overlap of explanatory variables. These findings provided the technical prerequisites and theoretical support for the benchmark regression model in the next section. The preliminary results appear to be in line with the study's expectations; however, further in-depth explorations and analyses are needed to gain a comprehensive understanding of the association.

4.4 | Regression Results

To explore the relationship between corporate carbon disclosure quality and the green bond issuance spread (Spread) in depth, this study conducted panel ordinary least squares regression with fixed-effects analyses of the underlying model, controlling for basic financial and bond characteristics and introducing year

dummy variables to account for fluctuations in the time dimension. The estimated results of the main regression model are presented in Table 5. The R^2 of the model is 0.4358 and the adjusted R^2 is 0.4168, indicating that the explanatory variables can explain more than 40% of the variance in green bond spreads with a good fit. The coefficient of the carbon disclosure quality score (CIDQ) is -7.73 , indicating that, when controlling for vintage characteristics, a one-rating-level increase in the quality of carbon disclosure will, on average, result in a reduction of the issuance spread of corporate green bonds by approximately 7.73 basis points. The data is found to be significant at the 5% level of confidence ($p=0.045$), thereby providing support for Hypothesis 1. This hypothesis posits that there is a negative relationship between the quality of carbon disclosure among firms and the spread they face when issuing green bonds, when controlling for the macro characteristics of the key vintage and the industry environment. This significant negative relationship suggests that, within the context of the market mechanism, investors are likely to perceive enterprises demonstrating superior environmental performance as having diminished risk and being more sustainable entities. Consequently, investors are expected to demand reduced risk premiums, thereby narrowing the spreads of green bond issuance (Ding et al. 2022; Benlemlih et al. 2018). This finding is consistent with the empirical results from the existing literature in European and American markets. For instance, Russo et al. (2021) observe that favourable

environmental performance can result in reduced financing costs through market channels.

In terms of control variables, the logarithmic term of market capitalisation ($\ln mc$) proved to be significant at the 1% level of significance, with a coefficient of -14.71 . This finding indicates that as the market capitalisation of the issuing entity increases, the issuance spread of its green bond decreases. This outcome aligns with prevailing expectations, as substantial enterprises often possess superior capabilities in terms of credit ratings, information disclosure and market liquidity, which consequently leads to reduced bond issuance costs (Tang and Zhang 2020). Meanwhile, the negative coefficient on firm size ($\ln mc$) is significantly correlated at the 1% level, suggesting that the market generally grants superior pricing conditions to larger firms. Notably, bond maturity (Tenor) is positively correlated with financing spreads, suggesting that the longer the maturity, the higher the spreads, possibly reflecting the impact of the longevity of green projects in conjunction with the liquidity premium (Ehlers and Packer 2017). The regression results demonstrate that there is no statistical significance for any of the four variables: the profitability variable (ROA), bond size (IA), bond maturity (Tenor) and the ratio of tangible assets (tar). This suggests that there may be a strong industry dependence in its effect on green bond spreads, and it is worthwhile to further explore the subgroup heterogeneity in the subsequent section.

In addition, the majority of the regression results for the year dummy variables are statistically significant, indicating a significant time-varying trend in green bond spreads at the macro level (see Table 6). Specifically, the year coefficients for the period from 2015 to 2020 are all negative and most of them hold at the 1% significance level, suggesting that firms with a higher quality of carbon disclosure have significantly lower financing costs in that period. The regression coefficient of 2016 (-82.80) is the most significant, reflecting the policy effects resulting from the initial establishment of China's green financial policy system, the introduction of green bond issuance norms and the initial launch of the carbon market mechanism (Wang and Zhang 2017). Since 2019, the negative magnitude of the year

TABLE 5 | Regression results.

| | Spread |
|--------------|----------------------------------|
| CIDQ | -7.730^{**} (-3.819) |
| ROA | -223.412 (-170.953) |
| $\ln mc$ | -14.714^{***} (-3.479) |
| IA | -0.145 (-0.877) |
| Tenor | 0.631 (-2.821) |
| tar | -21.866 (-21.538) |
| score_sector | 1.688^{***} (-0.591) |
| Constant | 290.552^{***} (-35.152) |
| Observations | 523 |
| Adj. R^2 | 0.4168 |
| Year FE | Yes |

Note: Standard errors are in parentheses.

** $p < 0.05$.

*** $p < 0.01$.

TABLE 6 | Regression results for year fixed effects.

| Year | Spread |
|------|--------------------------------|
| 2015 | -44.676^{***} (-4.738) |
| 2016 | -82.805^{***} (-18.078) |
| 2017 | -33.716 (-22.969) |
| 2018 | -9.563 (-22.672) |
| 2019 | -40.319^{**} (-18.144) |
| 2020 | -70.269^{***} (-21.365) |
| 2021 | -121.415^{***} (-14.637) |
| 2022 | -133.734^{***} (-12.871) |
| 2023 | -128.838^{***} (-15.092) |
| 2024 | -142.612^{***} (-14.532) |

Note: Standard errors are in parentheses.

** $p < 0.05$.

*** $p < 0.01$.

coefficients has increased, and their significance has continued to rise, indicating a gradual deepening of the impact of the quality of CID on green bond pricing. This phenomenon may be attributed to the ongoing promotion of green finance policies and the progressive enhancement of market mechanisms (Ding et al. 2022). Investors are increasingly cognisant of carbon information, and the market is becoming more efficient at identifying and pricing information. Overall, the findings indicate that the year dummy variables are significant, which validates the necessity of controlling for time-fixed effects. Furthermore, this result demonstrates the dynamic influence of carbon disclosure on the pricing mechanism of green bonds.

To test the difference in marginal effects of carbon disclosure quality across industries, this study introduces the interaction term variable 'score_sector', exploring the moderating role of industry-level factors on the cost of green bond financing. The regression results indicate that the industry average carbon disclosure score is statistically significant at the 1% level, with a coefficient of 1.69. This finding suggests that when the overall carbon disclosure level of the industry in which the firms are located is higher, individual firms are more likely to face higher spreads. This phenomenon may be indicative of the fact that the carbon intensity of the industry will affect green bond pricing.

4.5 | Heterogeneity Test

To further identify the industry heterogeneity effect of carbon disclosure on green bond pricing, this research categorises the sample firms based on their carbon emission intensity. The industries of Manufacturing, Energy & Water Supply, Mining, Transportation, Storage & Postal and Construction are categorised as high-carbon industries, whereas the remainder of the industries are viewed as low-carbon industries. The sample firms are then regressed separately in order to evaluate the differences in the marginal effects of carbon disclosure quality.

According to Table 7, in high-carbon industries, the effect of CIDQ on green bond financing spreads is significantly negative ($p < 0.05$, coefficient = -4.135). This suggests that firms' increased transparency in their carbon information has a significant impact on reducing financing costs. This result indicates that investors exhibit heightened sensitivity to environmental information in high-emission industries (Zhou et al. 2018; Basse Mama and Mandaroux 2022; Xu et al. 2024). Consequently, in these industries, carbon disclosure is more likely to be viewed as a sign of risk mitigation and a commitment to credibility. This, in turn, amounts to a financing advantage.

In contrast, CIDQ's regression coefficient of 6.782 ($p < 0.05$) in low-carbon industries suggests that higher financing spreads in those with lower emissions are unrelated to improved quality of carbon disclosure. This inverse relationship may be attributed to the fact that the conventional benefit of disclosure—reducing information asymmetry—is overshadowed by structural factors unique to low-carbon contexts. Firstly, investors may interpret high disclosure as excessive signalling or misallocated resources. In sectors with inherently low emissions, environmental performance is not a primary pricing driver. Consequently, higher CIDQ can trigger intensified scrutiny

TABLE 7 | Heterogeneity analysis: Regression results by carbon intensity.

| | High carbon Spread | Low carbon Spread |
|--------------|-----------------------------------|----------------------------------|
| CIDQ | -4.135^{**} (-1.907) | 6.782^{**} (-3.164) |
| ROA | -207.275^* (-113.945) | -118.348 (-417.955) |
| lmc | -15.831^{***} (-3.855) | -14.847^{***} (-3.962) |
| IA | -8.595 (-6.105) | -0.886 (-0.845) |
| Tenor | -0.451 (-2.189) | 0.001 (-1.832) |
| tar | -101.788^{***} (-21.007) | 62.843^* (-35.327) |
| Constant | 261.580^{***} (-20.711) | 145.331^{***} (-23.462) |
| Observations | 329 | 194 |

Note: Standard errors are in parentheses.

* $p < 0.1$.

** $p < 0.05$.

*** $p < 0.01$.

from ESG-focused investors. Rather than signalling operational efficiency, it may raise concerns about adverse selection risk, as investors question whether the firm is over-investing in visibility rather than fundamentals (Henide 2022). Secondly, the direct costs of compliance outweigh reputational benefits. High-quality carbon disclosure reveals the magnitude of transition costs, such as R&D investments and stringent regulatory compliance. The mandatory disclosures required for green bonds impose tangible verification and communication expenses. As Dutordoir et al. (2024) note, these costs can exceed the financing advantages gained from a greener profile, leading investors to price in these burdens via higher spreads.

In conclusion, the results further reveal the mechanism by which the quality of carbon disclosure influences the expense of green bond financing and demonstrate that there are significant structural differences in this mechanism across industries with different carbon emission intensities, highlighting the moderating role of industry attributes in the relationship between carbon disclosure and the price of green financing.

In summary, the regression results strongly support Hypothesis 1, which states that an improvement in the quality of carbon disclosure is associated with a decrease in the cost of green bond financing. Additionally, the model shows a satisfactory level of explanatory power. To further verify the robustness and applicability of the findings, the next section will perform a robustness analysis to strengthen confidence in causal identification.

TABLE 8 | Robustness test results.

| | Spread (1) | Spread (2) |
|---------------------|-------------------------|------------------------|
| ENVIRONMENTAL_SCORE | -9.864** (-3.919) | — |
| CDP_SCORE | — | -19.523** (8.632) |
| ROA | -153.978 (-129.138) | 32.806 (191.510) |
| lmc | -15.790** (-5.216) | -18.482*** (4.445) |
| IA | -0.745 (-0.998) | -0.551 (1.442) |
| Tenor | 1.508 (-3.577) | 7.598 (6.272) |
| tar | -21.888 (-16.343) | -0.404 (27.506) |
| score_sector | 1.567 (-1.17) | 3.425* (1.875) |
| Constant | 291.074*** (-43.832) | 259.431*** (40.451) |
| Observations | 317 | 203 |
| Adj. R^2 | 0.3765 | 0.4442 |
| Year FE | Yes | Yes |

Note: Standard errors are in parentheses.

* $p < 0.1$.

** $p < 0.05$.

*** $p < 0.01$.

4.6 | Robustness Test

To evaluate the robustness of the primary regression findings, this study improves the reliability of causal inference by substituting the main explanatory variables, ensuring that the results are not affected by specific measurement or sample selection biases. In this study, environmental disclosure scores and CDP scores from the Bloomberg database are used to replace the original carbon disclosure scores. To address concerns about construct validity, CDP scores are employed as an alternative measure of carbon disclosure to test the robustness of the findings. The regression results are presented in Table 8. Despite the substitution of variables, the key conclusion remains unchanged: There is a negative relationship between the quality of carbon disclosure and the cost of green bond financing, with a notably negative correlation coefficient. The economic implications are largely consistent with the initial regression. This finding indicates that the study's conclusions are not dependent on a particular indicator configuration and show a high level of robustness.

To mitigate endogeneity, we conduct sub-sample analysis by enterprise ownership (Table 9). The CIDQ coefficients vary

TABLE 9 | Regression results based on the nature of enterprises.

| | State-owned enterprises Spread | Private enterprises Spread |
|--------------|-----------------------------------|-------------------------------|
| CIDQ | -4.380* (2.323) | -12.059* (6.724) |
| ROA | -18.770 (126.706) | -239.516 (179.335) |
| lmc | -6.814*** (2.099) | -36.174*** (7.228) |
| IA | -1.005 (0.701) | 3.175 (3.809) |
| Tenor | 0.726 (1.162) | 5.837 (3.718) |
| tar | -27.598** (12.347) | 94.485* (53.052) |
| Constant | 130.751*** (14.425) | 300.150*** (32.532) |
| Observations | 410 | 113 |

Note: Standard errors are in parentheses.

* $p < 0.1$.

** $p < 0.05$.

*** $p < 0.01$.

significantly: -4.380* for SOEs and -12.059* for private firms. This divergence demonstrates that the relationship is ruling out spurious correlation driven by unobserved firm characteristics.

In summary, the present research verifies the stability and reliability of the primary regression results through the execution of robustness tests. Hypothesis 1 remains consistent across different testing conditions, indicating that the conclusions of this research have strong applicability for extrapolation and policy implications.

5 | Discussion and Conclusions

Drawing on data from 166 Chinese listed companies that issued green bonds from 2014 to 2024, we examined how CID quality affects financing costs. Our results show that CID quality influences green bond financing costs primarily through information and risk-assessment channels, rather than merely serving as a symbolic ESG disclosure. Consistent with information asymmetry, higher quality CID improves the credibility, comparability and verifiability of environmental data, thereby reducing uncertainty for bond investors (Sengupta 1998). In the context of green bonds, where investors are highly conscious of greenwashing risks, credible carbon disclosures tend to enhance confidence that bond funds support environmental objectives (Flammer 2020). This reduces perceived transition and reputational risks, leading to a lower risk premium from investors and

lower financing costs. The findings suggest that higher disclosure quality boosts transparency, which in turn diminishes perceived non-financial risk and affects the required return. Further analysis reveals that the impact of CID on financing costs varies notably across different carbon intensity levels, suggesting that investors are more responsive to environmental information in carbon-intensive industries, where carbon data plays a more prominent role in pricing (Zhou et al. 2018; Basse Mama and Mandaroux 2022). Additionally, in low-carbon industries, this relationship is reversed, implying that the market's response to CID is either weakened or misrepresented (Henide 2022).

The findings affirm that transparent and standardised CID can act as a credible signal for companies to demonstrate their environmental responsibility and low-carbon commitments in the capital market (Hu and Liang 2024). This signal enhances companies' environmental reputation; boosts investors' understanding and trust in the efficiency of fund utilisation, the environmental attributes of projects and compliance; and influences the reviewability and verifiability of relevant information (Biddle et al. 2009; Alsaifi et al. 2020). As a result, information asymmetry and expected risk decrease, capital allocation uncertainty lessens and companies are more likely to attract investors and secure favourable financing conditions (Benlemlih et al. 2018). The findings support Díaz and Escribano (2021), who argue that some investors possess social preferences and are willing to pay for social value. Consequently, as the effectiveness of CID improves and green characteristics become more verifiable, the share of such funds allocated to the green bond market is likely to be high, thereby increasing demand-side pricing power (Riedl and Smeets 2017). The significance of information asymmetry theory, signal transmission theory and social responsibility investment theory in the context of green bond pricing is further underscored. The empirical findings also support green finance theory, demonstrating broad credibility and explanatory power. This indicates that high-quality carbon emissions information can promote greater transparency and more favourable financing conditions by signalling environmental awareness, reducing information asymmetry and satisfying stakeholder needs (Flammer 2021; Hicks 2023). Consequently, this can reduce the financing costs of green bonds. The combined effect of these factors results in a significant negative correlation between the performance of CID and the costs of green bond financing. Our research indicates that improving the credibility of disclosures, through standardised reporting frameworks, third-party verification and stricter regulatory enforcement, can significantly affect investors' pricing decisions by reducing perceived information risk.

We conclude that carbon disclosure policies should be informed by the unique institutional context in which businesses operate, rather than by normative and pre-determined assumptions. The Chinese institutional context provides a distinctive setting to position this perspective. In particular, China's green bond market is evolving, with disclosure standards heavily shaped by state monitoring and inconsistent market oversight. Under such environments, investors are keen to focus on high-quality CID as a trustworthy indicator that distinguishes companies with genuine environmental commitment from those merely engaging in symbolic compliance. These implications are particularly

relevant in emerging markets, where formal ESG verification systems are still evolving, and state policy support may coexist with information opacity. Enhancing CID quality, therefore, not only ensures transparency but also serves as a governance signal that reinforces market discipline and builds investor confidence. Our study adds to the strand of literature on sustainable finance by emphasising that the significance of environmental disclosure pricing hinges not only on whether organisations disclose carbon details but also on the reliability, credibility and informational quality of that disclosure within a particular institutional setting.

Our study also has several implications for managers. It is crucial for corporate managers to recognise the key role of high-quality CID in enhancing corporate environmental transparency, building a green image and reducing information asymmetry. This is also vital for achieving sustainable development and lowering financing costs (Rehman et al. 2023). Companies can communicate their low-carbon transition commitments and environmental governance capabilities to investors through standardised, comprehensive CID, thereby alleviating concerns about information asymmetry and greenwashing (Flammer 2021). This may lead to stronger, more favourable green-financing conditions and greater recognition in the capital markets. For investors, the quality of CID can serve as a direct basis for measuring a company's environmental performance and sustainability strategy. High-quality carbon disclosure not only demonstrates a company's proactivity in environmental governance but also helps investors assess potential environmental risks and compliance levels, optimise investment decisions and improve portfolio stability (Riedl and Smeets 2017). For regulatory authorities, a CID system can greatly facilitate the fair pricing of green bonds. In promoting the development of a green financial system, regulators can enhance CID standards, moderately elevate disclosure requirements and guide enterprises to improve the quality of environmental information (Guenther et al. 2016).

Author Contributions

Siyang Wang: conceptualization, investigation, writing – original draft, methodology, validation, formal analysis. **Chaminda Wijethilake:** supervision, conceptualization, writing – review and editing.

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Conflicts of Interest

The authors declare no conflicts of interest.

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