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Doctoral Dissertation

Research on Structural and Sentiment Evolution of Corporate Sustainability Disclosure under China's "Dual Carbon" Goal: Evidence from Chinese-Listed Companies

XIE, Yuqi (謝 雨奇)

Supervisor KIM, Eunyoung

Division of Advanced Science and Technology
Japan Advanced Institute of Science and Technology
[Knowledge Science]

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Abstract

International efforts to address climate change have emphasized the necessity for achieving net-zero emissions by 2050. In alignment with these efforts, China introduced the “Dual Carbon” goal as a key climate and energy policy. Since companies are the primary actors in implementing this policy, this study examines the structural and sentiment evolution of sustainability reporting of Chinese-listed companies under the "Dual Carbon" goal, with a focus on changes in keyword emphasis, thematic structure, semantic centrality, and disclosure tone.

Drawing on a sample of 7860 sustainability disclosure (CSR, ESG, SD, and ENV) from 2019 to 2023, this study applies an integrated text analysis approach combining word frequency analysis, latent Dirichlet allocation (LDA) topic modeling, co-occurrence network analysis, and lexicon-based sentiment analysis. These methods enable a multidimensional examination of disclosure evolution from the perspectives of structure and sentiment.

The results show a clear pattern of structural expansion around the “Dual Carbon” goal in corporate sustainability disclosure. First, carbon-related keywords became significantly more prominent following the introduction of the “Dual Carbon” goal, indicating growing attention to climate-related policy concepts. Second, topic modeling results show that Climate & Emission Strategy emerged as the dominant thematic lineage, while Resource Utilization & Pollution Control declined in prominence, suggesting a transition in narrative logic toward climate-oriented strategic disclosure. Third, co-occurrence network analysis demonstrates that “Dual Carbon,” “Carbon Neutrality,” and “Carbon Peaking” evolved into central semantic hubs within disclosure networks, while concepts such as “Digitalization” and “Governance” functioned as key connectors linking climate-related topics with broader organizational and managerial clusters.

On the other hand, the study identifies a pattern of sentiment moderation. Although disclosure tone remained positive, both comprehensive sentiment scores and “Dual Carbon” semantic window sentiment scores exhibited a gradual decline over time. Furthermore, ownership-based analysis shows divergent sentiment trajectories between SOEs and non-SOEs. SOEs maintained a relatively stable disclosure tone, while non-SOEs exhibited a more pronounced decline in sentiment scores, suggesting different communication adjustments under evolving institutional and market conditions.

Overall, the findings suggest that the sustainability disclosure of Chinese-listed companies experienced a multidimensional evolution characterized by structural

expansion and sentiment moderation under the “Dual Carbon” goal. From an institutional perspective, this pattern reflects the adjustment of disclosure narratives to align with changing regulatory and normative expectations. From a signaling perspective, it reflects a calibrated communication strategy in which expanded carbon-related disclosure enhances signal visibility, while moderated disclosure tone strengthens signal credibility. In this way, the study provides a comprehensive account of how corporate sustainability disclosure evolves within a policy-driven institutional context.

Keywords: Sustainability Disclosure; Textual analysis; LDA; Co-occurrence Network; Sentiment Analysis; Chinese-listed companies; Institutional Pressure; Signaling visibility and Credibility

Acknowledgement

To my grandpa, I finally made it!

When I was in middle school, somehow I told my grandparents that I would get a doctoral degree in the future. They laughed, thinking it was just another daydream of their naughty grandson.

“You know, no one in our family has ever obtained a doctoral degree, even a master’s degree,” my grandpa said, “why don’t you get a more realistic goal?” Then he gently patted me on the head.

Honestly, I was really frustrated at that time since my grandpa was always supportive of all my decisions, but not this time. I forgot this incident very soon. Time just went by, I went to university and received my bachelor's degree, and then my grandpa’s passing, and then my master’s degree, and now my doctor’s degree.

Looking back, I now realize something important. I am deeply grateful to my **younger self**, who dared to picture a goal that everybody thought should be corrected.

“I feel like the odds are always in your favor because you just get everything you want as scheduled so easily that I can’t see any effort you made”. My mom insists on her point as usual. Obviously, it is indeed extremely difficult or embarrassing for a Chinese mother to praise or even recognize her son’s progress by telling what she is really thinking.

The truth is, I am clearly aware of how challenging and demanding the process of pursuing a doctoral degree has been. Seeking THAT research topic that interests you most, reading tons of literature, drafting a feasible research proposal, polishing professional skills, conducting research experiments, analyzing the results, drafting conference and journal manuscripts, finalizing the doctoral thesis, and defending the whole research, all of which have to be completed in three years.

The biggest challenge would be time management and perseverance. That’s why I sincerely hope to express my deepest gratitude to my supervisor, **Prof. KIM, Eunyoung**. She always reminds me of every single important milestone during my doctoral studies and instructs me to coordinate priorities among curriculum selection, lecture attendance, research design, internship schedule, manuscript polishing, and doctoral defense preparations. A sailor can never conquer the ocean without a compass. Luckily, Prof. Kim has served as my “compass” on this journey of navigating the academic ocean.

I sincerely appreciate **Prof. GOKON, Hideomi**, who is my second supervisor. I was impressively inspired by his classes, *K236 Basis of Data Science* and *K417 Data Analytics*, where I realized the power of data both in the real and academic worlds. In

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There is a viral slang regarding a Ph.D. student's studies and life. People say Ph.D. actually refers to Permanent Head Damage. Of course, this slang is a sort of self-teasing, and what we want to convey is just to laugh at the pain until we defeat it. Again, I truly thank all the professors who offered me guidance and support.

Well, the pain comes from the long-term and boring studies, but there were still lots of days as well when we would feel insecure, lost, depressed, and confused with the pressures from our daily life, like the blurred future, complicated human relationships, financial difficulty, cultural shock, moments of vulnerability, etc. I seriously considered giving up my doctoral studies several times. But fortunately, there were always nice families and friends holding me back.

A thousand thanks to my parents, who are **Mr. XIE, S.Y.**, and **Ms. LIAO, X.F.** I know that you would never tell how much you would love me, but you would forever remember to say, “Be a good boy! Stay at home and do not go out at midnight!” Well, I am just kidding. Seriously, I feel grateful that my parents are open-minded and keep encouraging me to pursue my dream of studying abroad with financial and spiritual support.

A thousand thanks to my grandma, **Ms. XIE, D.F.** Playing mahjong and card games together is a real cure for my stress.

A thousand thanks to my elder sister, **Ms. XIE, Y.H.** She always shares new local restaurants and weird but tasty food with me when I’m on vacation in my hometown.

Many thanks to my dear friend, **Dr. LIANG, Yilan**. I will never forget the days we called each other till late at night to complain about our dramatic and suffering doctoral

studies.

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Among the Chinese older generations, people would not say they will go to heaven after death. Instead, people would say they will go to see the dearest comrade, Karl Marx. I guess my grandpa would finally meet with Karl Marx and announce with pride and loudness that his grandson obtained a doctoral degree today, as I did in this acknowledgement.

Love you, Mom and Dad, and L.

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Chapter 1
Introduction

1.1 Research Background

Climate change, particularly global warming resulting from carbon emissions (CO_2), has been identified as an interdisciplinary issue affecting Economics, Sociology, Politics, Ecology, Engineering, and other fields (Scrieciu et al., 2013). International efforts on carbon emission reduction have been made, so that global annual emissions are expected to decrease to 25–30 Gt CO_2 by 2030 and to net-zero by 2050 (IPCC, 2023). More than 132 economies have committed to achieving net-zero emissions by 2050 and many have introduced local climate policies to mitigate carbon emissions, such as the carbon market (Abbasi & Ahmadi Choukolaei, 2023; Green et al., 2014). In the real world, global warming has drawn significant attention from the public and the administration among high-income and emerging economies. For high-income economies such as the EU and Japan, governments and sector associations have set emissions reduction as an essential indicator to evaluate domestic or even multinational firms' performance on dealing with the climate change issue; customers are encouraged to show a preference for decarbonized or low-carbonized products. For emerging economies like China and India, the administration regarded green development as a new direction to improve the quality of economic growth; domestic companies made actions to align with green development both in publicity and operation, hoping to enhance their products and services' competitiveness in international markets.

However, the Glasgow Agreement highlights that emerging economies, such as China and India (Valavanidis, 2021), may experience significant hardship in satisfying these goals. For instance, China's rapid economic growth is accompanied by huge energy consumption, which has thereby substantially increased CO_2 and other greenhouse gas emissions. Specifically, China is the largest energy consumer with the highest proportion of 23.6% in global total consumption, and its energy consumption structure is relatively unreasonable(Wen et al., 2021). As the world's largest developing economy and a major energy consumer and carbon emitter, China is expected to take the responsibility of reducing carbon emissions, even at a cost of weakening its robust economic growth. In response, China officially proposed the "Dual Carbon" Goal in 2020 at the 75th session of the United Nations General Assembly on 22 September 2020. In a more specific

clarification, the Chinese leadership has added to achieve a CO_2 emission peak by 2030 and to reach carbon neutrality (net zero carbon emissions) by 2060. To date, the "Dual-Carbon" Goal has become one of China's most important national strategies, especially in terms of Climate and energy policies.

Considering that companies and individuals are the primary actors in reacting to and practicing these goals(Carroll, 2017), it is worthy to explore their response at an academic level. In this study, Chinese-listed companies were chosen as the research focus. More specifically, since the "Dual-Carbon" goal emphasizes more on climate and energy policy, we perceived that sustainability disclosure, such as corporate sustainable report (CSR) and Environmental-Social-Governance report (ESG) were suitable raw data source. To explain, these reports are typically assumed as professional disclosures that reflect their commitment, preference, and response to address environmental, energy, and social issues(Carroll, 2017; Christensen et al., 2021). They often contain explicit information on how listed companies describe the alignment of their business visions with environmental and energy policies, such as the "Dual-Carbon" Goal.

However, simply observing the presence of such information is insufficient to capture the strategic depth of corporate responses. Within changing policy context, companies may increase the quantity of disclosure merely for compliance, potentially masking the lack of substantive strategic realignment. Beyond the volume of sustainability disclosure, its internal structure constitutes an important dimension for understanding how firms interpret and communicate sustainability priorities. Corporate sustainability disclosure is not merely a collection of isolated statements but represents a structured narrative system in which certain topics receive greater prominence, occupy more central positions, and establish stronger connections with other organizational concepts. Changes in narrative structure may reflect shifts in strategic focus, evolving institutional expectations, and the integration of new policy priorities into corporate communication frameworks. Prior research has emphasized that corporate disclosure narratives evolve over time as firms adjust thematic emphasis and reorganize disclosure content in response to changing external environments(Hahn & Kühnen, 2013; Niamh & Doris, 2007). In this sense, examining structural evolution—including changes in keyword prominence, thematic composition, and semantic centrality—provides insight into how sustainability issues are incorporated into the core narrative logic of corporate disclosure. Such structural analysis enables a more comprehensive understanding of disclosure evolution beyond simple changes in disclosure quantity.

Apart from structural organization, the sentiment or tone of corporate sustainability disclosure represents another important dimension of corporate communication.

Disclosure tone reflects how firms frame sustainability issues, express strategic positioning, and convey confidence or caution in relation to policy and environmental commitments. Prior studies in accounting and corporate communication research have demonstrated that textual tone provides meaningful information about managerial perspectives and organizational communication strategies(Henry, 2008; Loughran et al., 2011). In sustainability contexts, tone may be particularly relevant because environmental commitments often involve forward-looking goals, policy alignment, and implementation uncertainty. As firms incorporate new policy-related priorities such as the "Dual Carbon" goal into sustainability disclosure, changes in disclosure tone may reflect adjustments in communicative strategy and narrative framing. Examining sentiment evolution alongside structural changes therefore provides a more complete perspective on how corporate sustainability disclosure develops under emerging climate or energy policy environments.

However, an important research problem still remains. Although sustainability disclosure is often regarded as a professional channel through which firms communicate their environmental commitments and policy alignment, it is still unclear whether and how such disclosure reflects corporate responses to the "Dual Carbon" goal over time. This issue cannot be sufficiently understood from disclosure quantity alone, because policy-related adjustments may also appear in the internal structure of disclosure and in the tone through which sustainability issues are communicated. Therefore, this study defines its research problem as *"how the sustainability reporting of Chinese-listed companies evolved under the "Dual Carbon?"*

Against this background, the motivation of the present study lies in two related considerations. First, the "Dual Carbon" goal represents a major policy transition in China and provides an important institutional context for observing how firms respond to emerging climate and energy priorities. Second, sustainability reports provide a particularly suitable empirical entry point because they function as public and policy-relevant communication channels through which firms articulate environmental commitment, strategic orientation, and organizational positioning. These considerations together motivate the present study to examine the structural and sentiment evolution of corporate sustainability disclosure under the "Dual Carbon" goal.

1.2 Research Objectives and Questions

To address the research problem identified above, this study develops a set of research objectives and research questions to examine how corporate sustainability disclosure evolved under the "Dual Carbon" goal. The overall aim of this study is to explore *how the sustainability reporting of Chinese-listed companies evolved structurally and*

sentimentally under the "Dual Carbon" goal and to interpret these disclosure changes through institutional and signaling perspectives. This overall aim can be further divided into three specific research objectives.

The first objective*(SRO1)* is to *analyze the structural evolution of corporate sustainability disclosure under the "Dual Carbon" goal*. This objective focuses on how disclosure priorities, thematic organization, and semantic relationships changed over time as firms adjusted their sustainability communication within an evolving climate policy environment.

The second objective*(SRO2)* is to *examine the sentiment evolution of corporate sustainability disclosure under the "Dual Carbon" goal.* This objective focuses on how disclosure tone developed over time and how firms adjusted the expressive framing of sustainability-related issues in response to policy-related uncertainty and communication needs.

The third objective*(SRO3)* is to *interpret the observed disclosure evolution through institutional theory and signaling theory*. This objective aims to explain why disclosure structure and disclosure sentiment evolved in particular directions under the policy context of the "Dual Carbon" goal, and how these changes may reflect legitimacy alignment, strategic communication, and organizational response under information asymmetry.

Based on these objectives, this study aims to answer the main research question: *How has the sustainability reporting of Chinese listed companies evolved structurally and sentimentally under the "Dual Carbon" goal?* Specifically, we decompose this into four sub-questions:

- *SRq1: Did carbon-related keywords display a significant rise following the introduction of the "Dual Carbon" goal?*
- *SRq2: How did the main themes of corporate sustainability disclosure evolve?*
- *SRq3: How did the central positions of keywords in corporate sustainability disclosure change?*
- *SRq4: How did disclosure tone toward the "Dual Carbon" goal evolve?*
  - *SEq4.a：How did the tone of "Dual Carbon" related disclosure compare with the overall tone of corporate sustainability disclosure?*
  - *SRq4.b：How did the tone of "Dual Carbon" related disclosure differ between SOEs and non-SOEs over time?*

To explain, the four sub-research questions are designed to capture different aspects of disclosure evolution, corresponding to complementary analytical perspectives.

SRQ1 focuses on changes in the prominence of carbon-related keywords following the introduction of the "Dual Carbon" goal. Keyword prominence reflects the degree of attention allocated to specific policy-related concepts within corporate disclosure. Examining whether carbon-related keywords displayed a significant rise provides an initial indication of whether climate-related policy priorities became more visible within sustainability reporting. This question serves as a foundational indicator of disclosure attention dynamics and provides a basis for subsequent structural analysis.

SRQ2 examines how the main themes of corporate sustainability disclosure evolved over time. Corporate sustainability disclosure consists of multiple thematic components, including environmental management, resource utilization, climate strategy, governance, and technological innovation. Topic evolution analysis enables the identification of shifts in thematic emphasis and narrative priorities or logics. By examining how thematic structures change, this question addresses whether sustainability disclosure underwent broader narrative transformation under the "Dual Carbon" policy environment.

SRQ3 investigates how the structural positions of keywords changed within the semantic network of corporate sustainability disclosure. While keyword frequency reflects attention allocation, semantic network centrality reflects structural importance within the narrative system. Keywords occupying central positions play a more significant role in organizing disclosure narratives and connecting different thematic domains. Examining changes in semantic centrality provides insight into how carbon-related concepts became integrated into the broader disclosure structure.

SRQ4 focuses on the evolution of disclosure tone toward the "Dual Carbon" goal. In addition to structural organization, disclosure tone represents an important dimension of corporate communication. Sentiment analysis enables the examination of how firms frame sustainability-related content and how expressive tone evolves as policy-related concepts become more prominent. By examining sentiment evolution within policy-specific semantic contexts, this question captures changes in the communicative framing of sustainability disclosure.

Taken together, SRQ1–SRQ3 address the structural evolution of corporate sustainability disclosure, including changes in attention allocation, thematic organization, and semantic structure. SRQ4 complements this structural perspective by examining sentiment evolution, providing insight into how disclosure tone developed alongside structural transformation. In this way, the research objectives define the main analytical dimensions of the study, while the research questions specify the empirical aspects to be

examined. The logical relationships among the research problem, research objectives, research questions, and theoretical interpretation are summarized in Figure 1.

In this study, the research problem, research objectives, research questions, and theoretical interpretation are organized within a coherent analytical logic. The research problem defines the central issue to be examined, while the research objectives specify the main dimensions of analysis, including structural evolution, sentiment evolution, and theoretical interpretation. Based on these objectives, the research questions identify the specific empirical aspects of disclosure evolution to be examined. The corresponding findings are then interpreted through institutional theory and signaling theory in the discussion chapter. The logical relationships among these components are summarized in Figure 1.

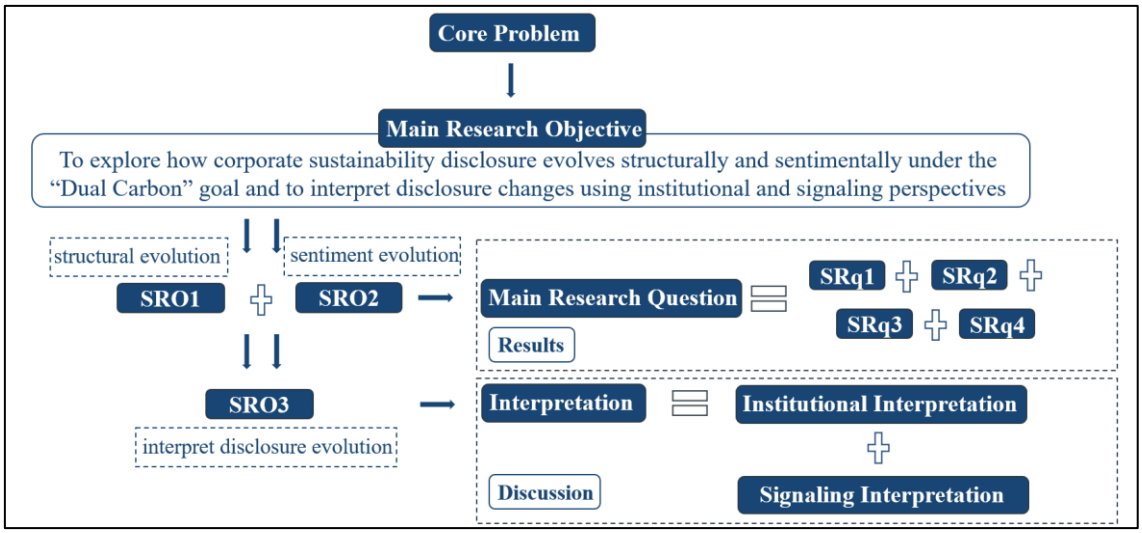

Figure 1: Analytical mapping of the research design

1.3 Research Contributions

This study contributes to the literature on corporate sustainability disclosure and policy-related communication in several important ways.

First, this study provides a comprehensive structural analysis of how corporate sustainability disclosure evolved under the "Dual Carbon" goal by applying multiple text analysis techniques to firm-level disclosure data. While existing studies have extensively examined policy texts or firm-level economic outcomes, relatively limited attention has been paid to how corporate sustainability narratives themselves evolve structurally in response to major climate policy initiatives. By examining keyword prominence, thematic evolution, and semantic network structure, this study offers a systematic analysis of how carbon-related concepts became increasingly integrated into corporate sustainability disclosure. This structural perspective contributes to a deeper

understanding of how corporate disclosure adapts to emerging climate policy priorities.

Second, this study extends existing research by incorporating sentiment analysis to examine how disclosure tone evolved alongside structural changes in sustainability reporting. Prior research on corporate sustainability disclosure has primarily focused on disclosure quantity, thematic content, or compliance indicators, with less attention to how disclosure tone develops in response to policy-related communication contexts. By combining structural analysis with sentiment analysis, this study provides a more comprehensive perspective on disclosure evolution. This integrated approach enables examination of how corporate sustainability disclosure evolves across both structural and expressive dimensions, offering a more complete understanding of disclosure dynamics.

Third, this study contributes methodologically by integrating keyword frequency analysis, topic modeling, semantic network analysis, and sentiment analysis within a unified analytical framework. Existing studies often apply these techniques independently to examine specific aspects of disclosure. By combining multiple complementary methods, this study enables analysis of disclosure evolution from multiple structural levels, including attention allocation, thematic organization, semantic connectivity, and expressive tone. This integrated methodological framework enhances the ability to capture complex changes in corporate sustainability disclosure over time.

Fourth, this study contributes to the application of institutional theory and signaling theory in the context of corporate sustainability disclosure under climate policy environments. While prior research has applied these theories extensively in corporate disclosure and organizational communication research, their application to climate policy–related sustainability disclosure evolution remains limited. By examining corporate sustainability disclosure in the context of a major national climate policy initiative, this study provides an interpretive framework for understanding how disclosure structures and communication patterns evolve within changing institutional and signaling environments.

Finally, this study contributes empirical evidence from Chinese-listed companies, providing insights into how corporate sustainability disclosure evolves within the context of emerging climate governance frameworks. As China represents one of the world's largest emerging economies and has introduced ambitious climate policy goals, examining disclosure evolution within this context provides valuable empirical insights into corporate sustainability communication under large-scale policy transformation.

1.4 Research Framework

To address these research questions within a coherent theoretical and analytical logic,

this study develops a conceptual framework grounded in institutional and signaling theory, as illustrated in Figure 2. The framework organized in the logic of Context-Process-Outcome illustrates how institutional pressure associated with the "Dual-Carbon" goal is conceptually linked to changes in corporate sustainability disclosure and how this process is investigated through text-based analytical methods.

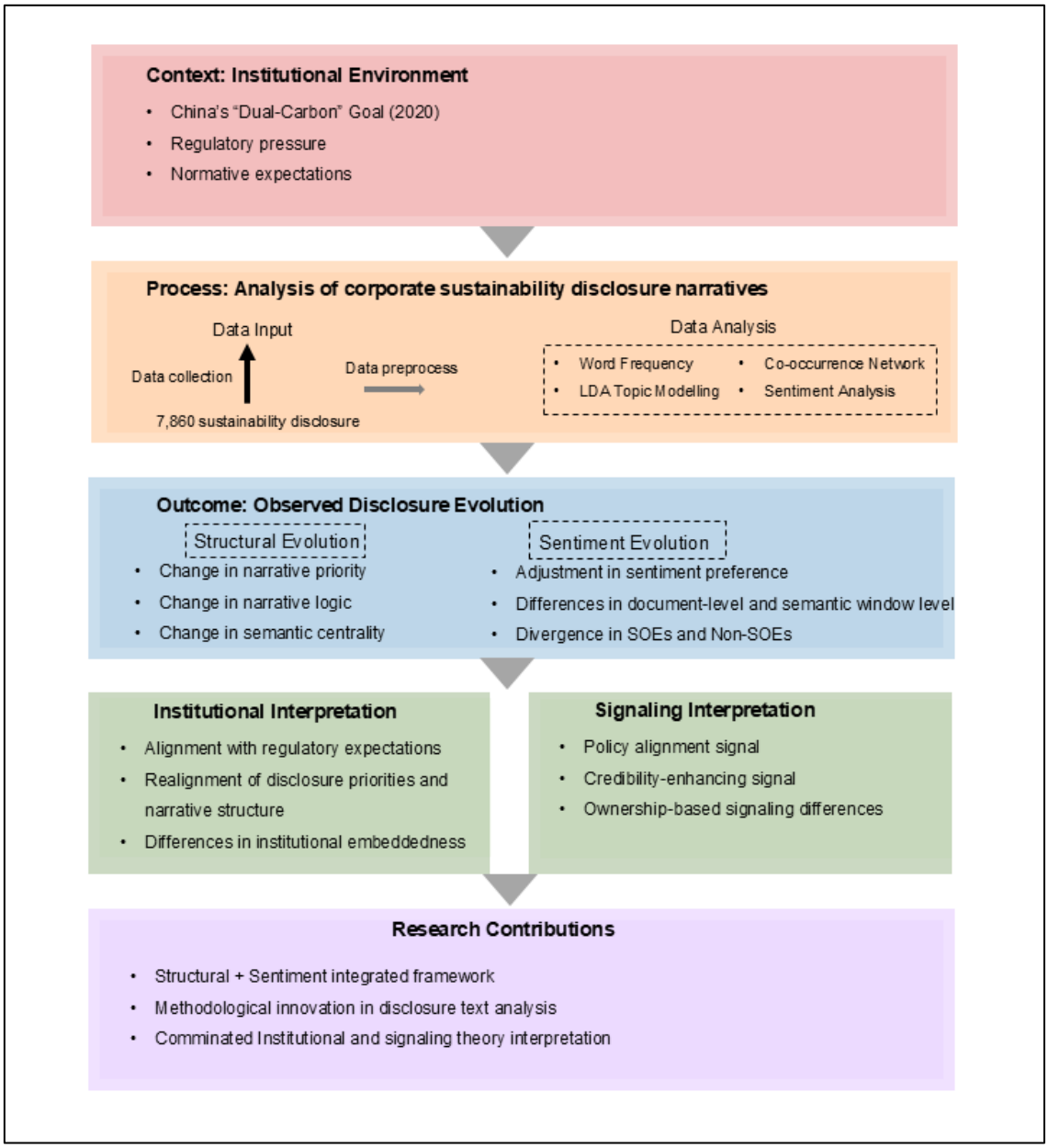

Figure 2: Framework

Chapter 2
Literature Review

2.1 Institutional Theory Context

2.1.1. Institutional Theory Foundations

Institutional theory provides a foundational perspective for understanding how organizations adapt their practices and communication strategies in response to external pressures arising from regulatory, normative, and cognitive environments. The central premise of institutional theory is that organizational behavior is shaped not only by efficiency considerations but also by the need to achieve legitimacy within a socially constructed institutional framework (DiMaggio & Powell, 2000; W. R. Scott, 2023).

According to Scott (2023), institutions consist of three mutually reinforcing pillars: the regulative pillar, the normative pillar, and the cultural–cognitive pillar. The regulative pillar refers to formal rules, laws, and policy instruments that constrain and guide organizational behavior through coercive mechanisms. The normative pillar reflects social expectations, professional standards, and value systems that define appropriate organizational conduct. The cultural–cognitive pillar represents shared beliefs and interpretive frameworks that influence how organizational actors perceive and respond to their environment. Together, these institutional pillars shape organizational decision-making processes and influence how firms structure their actions and communications.

Within institutional environments, organizations are subject to multiple forms of institutional pressure that influence organizational behavior and strategic responses. DiMaggio and Powell (2000) identify three primary mechanisms through which institutional pressures operate: coercive isomorphism, normative isomorphism, and mimetic isomorphism. Coercive isomorphism arises from formal regulatory requirements and policy mandates imposed by governmental authorities or regulatory bodies. Normative isomorphism emerges from professional norms and industry standards that shape expectations regarding appropriate organizational practices. Mimetic isomorphism occurs when organizations imitate the behavior of other organizations perceived as legitimate or successful, particularly under conditions of uncertainty.

These institutional pressures encourage organizations to align their structures, practices, and symbolic actions with prevailing institutional expectations in order to secure

legitimacy, resources, and long-term survival(Meyer & Rowan, 2021; Suchman, 1995). Meyer and Rowan (2021) argue that organizational structures and practices often reflect institutionalized myths and socially accepted norms, which organizations adopt to demonstrate conformity with institutional expectations, even when such practices may not directly improve operational efficiency. In this context, organizational behavior can be understood as a process of institutional conformity aimed at maintaining legitimacy and securing continued access to resources and stakeholder support.

Institutional theory further emphasizes the role of legitimacy as a critical driver of organizational behavior. Legitimacy refers to the generalized perception that an organization's actions are appropriate and desirable within a socially constructed system of norms, values, and beliefs(Suchman, 1995). Organizations actively seek to maintain legitimacy by aligning their visible practices and symbolic representations with institutional expectations. Corporate disclosure represents one of the primary channels through which organizations communicate their conformity with institutional norms and signal their alignment with regulatory and societal expectations.

Institutional environments are not static but evolve over time in response to policy changes, regulatory developments, and broader socio-economic transformations. When new policies or regulatory frameworks are introduced, organizations may adjust their practices and communication strategies to align with emerging institutional expectations. This process of institutional adaptation often involves gradual changes in organizational structures, priorities, and symbolic communication practices, including corporate disclosure narratives(Marquis & Qian, 2014; W. R. Scott, 2023). As institutional expectations evolve, organizations recalibrate their disclosure strategies to maintain legitimacy and demonstrate alignment with dominant policy priorities.

In the context of sustainability and environmental governance, institutional theory has been widely applied to explain how firms respond to environmental regulations and policy initiatives through adjustments in corporate sustainability disclosure(Delmas et al., 2008; Marquis et al., 2016). Firms operating within environments characterized by strong regulatory intervention and policy guidance may face heightened institutional pressure to demonstrate alignment with national sustainability objectives. Under such conditions, corporate disclosure serves as an important mechanism through which firms signal conformity with institutional expectations and reinforce their legitimacy within the institutional system.

Taken together, institutional theory provides a comprehensive theoretical framework for understanding how organizational behavior and corporate disclosure practices evolve under changing institutional conditions. By emphasizing the role of legitimacy,

institutional pressure, and symbolic conformity, institutional theory offers valuable insights into how corporate sustainability disclosure may evolve in response to major policy initiatives such as the “Dual Carbon” goal.

2.1.2. Corporate Disclosure under Institutional Context

Institutional theory suggests that corporate disclosure evolves in response to changes in regulatory environments, social norms, and stakeholder expectations(W. Scott, 2013). When institutional pressures intensify, organizations tend to adjust their disclosure content, emphasis, and structure to reflect emerging institutional priorities. Disclosure practices therefore serve as visible indicators of how organizations interpret and respond to institutional signals. In this sense, corporate reporting can be understood as an institutionalized practice that reflects broader transformations in the regulatory and normative environment.

Prior research has demonstrated that institutional pressures play a critical role in shaping corporate disclosure behavior, particularly in the context of environmental and sustainability reporting. Firms operating in environments characterized by strong regulatory oversight and policy intervention often increase disclosure related to policy-relevant topics to demonstrate compliance and maintain legitimacy(Delmas et al., 2008; Marquis & Qian, 2014). For example, Marquis and Qian (2014) show that Chinese firms expanded their corporate social responsibility disclosure following the introduction of government reporting guidelines, highlighting the influence of regulatory pressure on disclosure practices. These findings suggest that corporate disclosure evolves in close alignment with institutional expectations, particularly in policy-driven institutional environments.

Institutional pressures influence corporate disclosure through multiple mechanisms. Coercive pressures arising from government regulations and policy mandates encourage organizations to disclose information aligned with regulatory priorities. Normative pressures stemming from professional standards and societal expectations further shape disclosure practices by defining what constitutes appropriate and responsible corporate behavior. Mimetic pressures may also lead organizations to adopt disclosure practices observed among peer organizations perceived as legitimate or successful(DiMaggio & Powell, 2000). These mechanisms collectively contribute to convergence in disclosure practices across organizations operating within the same institutional environment.

Corporate disclosure also plays an important role in the construction and maintenance of organizational legitimacy. Legitimacy is essential for securing access to resources, maintaining stakeholder trust, and ensuring long-term organizational survival(Suchman,

1995). Disclosure provides organizations with a platform to communicate their alignment with institutional expectations and to reinforce their legitimacy in the eyes of regulators, investors, and the public. Through disclosure, organizations present narratives that demonstrate their responsiveness to institutional priorities and their commitment to socially valued goals.

In the context of sustainability and environmental governance, corporate sustainability disclosure has become an increasingly important channel through which organizations demonstrate alignment with institutional expectations related to environmental responsibility. Environmental regulations and climate policy initiatives have created new institutional pressures that influence how organizations structure and communicate sustainability information(Clarkson et al., 2008; Hahn & Kühnen, 2013). Firms often adjust their sustainability disclosure to reflect policy priorities, regulatory requirements, and evolving societal expectations regarding environmental performance.

Institutional environments characterized by strong state involvement, such as China, provide a particularly important context for examining institutional influences on corporate disclosure. In such environments, government policy initiatives play a central role in shaping organizational priorities and disclosure practices(Marquis et al., 2011; Marquis & Qian, 2014). Chinese-listed companies operate within a regulatory system where policy signals carry substantial influence, and corporate disclosure often reflects alignment with national strategic priorities. As a result, changes in major policy initiatives may be associated with corresponding adjustments in corporate disclosure structure, emphasis, and narrative organization.

Institutional theory further suggests that organizational responses to institutional change may involve gradual adjustments in disclosure priorities, thematic focus, and symbolic communication practices(W. Scott, 2013). Rather than representing abrupt transformations, disclosure evolution often reflects an ongoing process of institutional adaptation in which organizations recalibrate their communication strategies to align with emerging institutional expectations. This process may involve changes in the prominence of specific topics, shifts in thematic emphasis, and adjustments in how organizational activities are framed and communicated.

Therefore, corporate sustainability disclosure can be understood as an institutionalized communicative practice that reflects how organizations interpret and respond to evolving institutional environments. By examining changes in disclosure structure, thematic emphasis, and communication patterns, researchers can gain insight into how organizations adapt to major institutional developments, including environmental policy initiatives such as the “Dual Carbon” goal. Institutional theory therefore provides a

relevant and robust theoretical framework for interpreting how corporate sustainability disclosure evolves under changing policy and regulatory conditions.

2.2 Signaling Theory Context

2.2.1. Signaling Theory Foundations

Signaling theory originates from the economics literature on information asymmetry and was first formally introduced by Spence (1973) in the context of labor market signaling. The core premise of signaling theory is that information asymmetry exists between informed and uninformed parties, and informed actors may strategically disclose signals to convey private information about their quality, intentions, or capabilities. In situations where stakeholders cannot directly observe underlying attributes or future performance, signals serve as communicative devices that reduce uncertainty and shape perceptions.

Information asymmetry constitutes the foundational condition of signaling behavior. In capital markets and organizational contexts, firms typically possess more information about their internal strategies, performance, and risk exposure than external stakeholders such as investors, regulators, and the public. Because stakeholders cannot fully verify internal conditions, firms may strategically provide observable indicators that help external audiences form assessments of organizational credibility and quality(Connelly et al., 2011). Corporate disclosure therefore functions as a key signaling mechanism in environments characterized by uncertainty and incomplete information.

A central concept in signaling theory is signaling cost. For a signal to be credible, it must involve a cost or constraint that differentiates high-quality actors from low-quality actors(Spence, 1973). If signaling is costless, low-quality actors could easily mimic high-quality actors, thereby undermining the informational value of the signal. Cost can take multiple forms, including financial expenditure, reputational risk, regulatory exposure, or future performance obligations. Signals that are difficult or risky to imitate are more likely to be interpreted as credible by signal receivers(Connelly et al., 2011). Consequently, signaling strategies often reflect a trade-off between visibility and credibility.

Another key component of signaling theory concerns signal receivers. Signals are inherently relational; their meaning depends on how they are interpreted by target audiences. Different stakeholders may evaluate the same signal differently depending on their expectations, informational needs, and institutional position. In corporate contexts, signals may be directed toward investors seeking financial performance indicators, regulators evaluating compliance, or broader societal audiences assessing corporate

responsibility. The identity of the signal receiver shapes both the content and intensity of signaling behavior.

Corporate disclosure has been widely conceptualized as a signaling mechanism in financial and sustainability contexts. Voluntary disclosure, in particular, has been interpreted as a signal of transparency, performance quality, or managerial confidence (Healy & Palepu, 2001). Firms may increase disclosure when they seek to differentiate themselves from competitors or reduce perceived uncertainty in the market. In sustainability reporting, disclosure may function as a signal of environmental commitment, strategic alignment, or long-term orientation(Clarkson et al., 2008). Under this perspective, corporate communication reflects strategic considerations related to reputation, credibility, and stakeholder evaluation.

Signaling behavior may also vary across organizational types. Firms facing higher information asymmetry or greater financing constraints may have stronger incentives to provide credible signals to external stakeholders. Conversely, organizations that enjoy reputational backing or institutional endorsement may rely less heavily on costly signaling to establish credibility. Differences in resource access, regulatory exposure, and stakeholder expectations can therefore produce heterogeneity in signaling strategies across firms.

In emerging markets and policy-intensive environments, signaling theory offers a useful lens for interpreting corporate responses to major policy initiatives. When governments introduce new policy priorities, firms may adjust disclosure practices to signal alignment with regulatory expectations or to reassure market participants regarding future compliance and strategic direction. At the same time, the credibility of such signals depends on perceived signaling costs and the institutional context in which they are embedded. Signals that expose firms to reputational or regulatory risk may carry greater informational value, particularly when scrutiny intensifies.

Taken together, signaling theory provides a structured framework for understanding how organizations communicate under conditions of uncertainty. By focusing on information asymmetry, signaling cost, and audience interpretation, the theory highlights how disclosure strategies reflect strategic positioning and credibility management. In the context of corporate sustainability disclosure under the “Dual Carbon” goal, signaling theory offers a complementary perspective to institutional theory, emphasizing how firms may calibrate both the content and tone of disclosure to convey credible alignment with evolving policy expectations.

2.2.2. Corporate Disclosure under Signaling Context

Corporate disclosure has been widely interpreted as a signaling mechanism through which firms communicate private information and strategic intentions to external stakeholders under conditions of information asymmetry. In financial markets, disclosure plays a central role in reducing uncertainty by providing observable indicators of firm performance, governance quality, and future prospects(Healy & Palepu, 2001). When stakeholders cannot directly observe internal organizational conditions, disclosure serves as an intermediary channel that helps shape external perceptions and assessments.

Voluntary disclosure is particularly relevant in signaling contexts, as firms may strategically provide additional information beyond mandatory requirements to differentiate themselves from competitors. Prior research suggests that firms with stronger performance, superior governance, or clearer strategic direction are more likely to disclose information voluntarily in order to signal credibility and reduce perceived risk (Dye, 1985; Verrecchia, 1983). Conversely, firms facing greater uncertainty or higher scrutiny may adopt more cautious disclosure strategies to avoid signaling commitments that could expose them to future accountability risks.

Sustainability disclosure represents a specialized form of corporate signaling, especially in contexts where environmental performance and long-term strategic alignment are difficult to observe directly. Environmental and sustainability reports provide signals regarding corporate environmental responsibility, regulatory alignment, and strategic orientation toward emerging policy priorities(Clarkson et al., 2008). In this sense, sustainability disclosure functions as a mechanism through which firms communicate their positioning within evolving institutional and regulatory environments. The presence, emphasis, and framing of sustainability-related information may therefore reflect signaling considerations related to legitimacy, credibility, and stakeholder expectations.

Disclosure tone constitutes an important signaling dimension in corporate communication. Beyond the presence of specific information, the tone of disclosure may convey implicit signals regarding managerial confidence, risk exposure, and strategic certainty. Prior studies have shown that firms adjust disclosure tone to influence investor perception and signal underlying organizational conditions(Henry, 2008; Loughran et al., 2011). A more confident tone may signal optimism and strategic clarity, while a more cautious tone may reflect uncertainty, regulatory sensitivity, or the presence of potential risks. As a result, disclosure tone provides an additional signaling layer beyond disclosure volume or content.

Signaling theory also highlights that signaling strategies may vary depending on organizational characteristics and institutional positioning. Firms facing higher levels of information asymmetry or weaker external credibility may rely more heavily on disclosure signals to reduce uncertainty and maintain stakeholder confidence(Connelly et al., 2011). In contrast, firms with stronger institutional backing or established reputational legitimacy may experience lower signaling pressure. These differences suggest that signaling behavior is shaped by organizational context, including ownership structure, regulatory exposure, and stakeholder composition.

In policy-intensive environments, corporate disclosure may function as a signal of policy alignment and regulatory responsiveness. When governments introduce new strategic priorities, firms may incorporate policy-related concepts into disclosure narratives to communicate awareness, compliance readiness, and strategic positioning. The integration of policy-specific terminology, strategic framing, and disclosure tone can therefore be interpreted as part of a broader signaling process through which firms communicate their alignment with evolving institutional expectations.

In the context of sustainability disclosure under major climate policy initiatives, signaling considerations may influence both the structural organization and expressive characteristics of corporate disclosure. Firms may increase the prominence of policy-related concepts to signal strategic alignment, while adjusting disclosure tone to maintain credibility under heightened regulatory scrutiny. These signaling dynamics highlight that corporate sustainability disclosure reflects not only informational reporting but also strategic communication shaped by stakeholder evaluation and institutional context.

Above, signaling theory provides an important complementary perspective for interpreting corporate sustainability disclosure. While institutional theory emphasizes legitimacy-seeking behavior under external pressure, signaling theory focuses on how firms strategically communicate information to reduce uncertainty and influence stakeholder perception. This perspective is particularly relevant for understanding how Chinese-listed companies may adjust disclosure structure and tone in response to evolving policy priorities such as the “Dual Carbon” goal.

2.3 Corporate Sustainability Disclosure & Narrative Evolution

Corporate sustainability disclosure has evolved substantially over recent decades, reflecting changing institutional expectations, regulatory environments, and stakeholder demands. Sustainability reports, corporate social responsibility (CSR) reports, and

environmental, social, and governance (ESG) disclosures have become important channels through which firms communicate their environmental commitments, strategic priorities, and organizational legitimacy(Gray et al., 1995; KPMG, 2020) . These disclosures function as a key interface between firms and external stakeholders, providing observable representations of corporate positioning within broader sustainability and policy contexts.

Early research on corporate sustainability disclosure primarily focused on disclosure volume and frequency. Studies examined whether firms increased the quantity of environmental information disclosed over time and how disclosure volume varied across industries, regulatory environments, and firm characteristics(Cho & Patten, 2007; Clarkson et al., 2008). While such approaches provided important insights into disclosure expansion, they often treated disclosure as a static phenomenon and did not fully capture changes in narrative organization or thematic emphasis. Subsequent research has increasingly emphasized the narrative dimension of corporate sustainability disclosure. Sustainability reports are not merely collections of isolated information but structured narratives that reflect how firms interpret and communicate their environmental and strategic priorities(Niamh & Doris, 2007). Narrative evolution may manifest through shifts in thematic emphasis, changes in conceptual framing, and the reorganization of disclosure structure. These changes provide important insights into how firms adapt disclosure practices in response to evolving institutional environments.

Textual analysis methods have played an important role in examining narrative evolution in corporate disclosure. Word frequency analysis has been widely applied to identify changes in the prominence of specific sustainability-related concepts over time (F. Li, 2010; Loughran & Mcdonald, 2016). By tracking the relative frequency of policy-related or environmental keywords, researchers can examine how firms adjust disclosure attention in response to emerging regulatory priorities or stakeholder expectations. Increases in the frequency of specific concepts may indicate growing strategic emphasis or alignment with dominant policy agendas.

Topic modeling techniques, particularly Latent Dirichlet Allocation (LDA), have further advanced the analysis of disclosure narratives by enabling systematic identification of underlying thematic structures. LDA allows researchers to identify latent topics within large textual corpora and examine how topic prevalence evolves over time (Blei et al., 2003). In sustainability disclosure research, topic modeling has been used to identify dominant environmental themes, trace shifts in corporate sustainability priorities, and examine how firms reorganize disclosure narratives under changing regulatory and institutional conditions(Dyer et al., 2017). These methods provide a more comprehensive

understanding of narrative evolution beyond individual keyword frequency.

In addition to thematic identification, recent studies have increasingly applied semantic network analysis to examine the structural organization of disclosure narratives. Co-occurrence network analysis enables researchers to analyze relationships between concepts by examining how frequently keywords appear together within textual contexts(Kathleen & Jana, 2005). The structural position of keywords within semantic networks, including centrality and connectivity measures, provides insight into how concepts function within disclosure narratives. Keywords that occupy central positions or serve as connectors between thematic clusters may play important roles in organizing disclosure structure and integrating different sustainability-related topics.

Semantic network analysis has been applied in sustainability research to examine how environmental concepts are integrated into corporate disclosure and how narrative structures evolve over time(Lee & Jung, 2019). Changes in keyword centrality, network connectivity, and cluster structure can reveal shifts in disclosure priorities and conceptual organization. This structural perspective complements frequency-based and topic-based approaches by capturing relational dynamics between disclosure concepts.

More recent research has emphasized that sustainability disclosure evolution reflects broader institutional and strategic adaptation processes. Firms adjust disclosure narratives to align with evolving policy priorities, stakeholder expectations, and regulatory frameworks(Cho et al., 2015; Hahn & Kühnen, 2013). Narrative evolution may involve the incorporation of new policy-related concepts, the restructuring of thematic priorities, and changes in how sustainability issues are integrated into broader corporate communication. These adjustments reflect ongoing interactions between institutional environments and corporate disclosure practices.

To be concerned, in adjacent fields such as accounting, finance, and corporate disclosure research, advanced text analytics and machine learning methods have increasingly been applied to tasks such as classification, risk detection, impression management analysis, and the identification of misleading or strategically framed reporting(Edgar et al., 2018; Muñoz-Izquierdo et al., 2022; Yang & Liu, 2017). These studies demonstrate the growing relevance of computational approaches in disclosure analysis. However, the analytical objective of the present study is different. The focus here is not on detecting deceptive or beautified disclosure, but on examining how sustainability disclosure evolves structurally and sentimentally under a major climate policy context. In this sense, the present study is methodologically related to the broader disclosure analytics literature, while its empirical objective remains centered on policy-driven disclosure evolution. Despite the growing application of textual analysis methods

in sustainability disclosure research, relatively limited attention has been paid to how major national policy initiatives influence the structural evolution of corporate disclosure narratives, particularly in emerging economies. Policy-driven sustainability transitions may reshape disclosure priorities, thematic organization, and semantic structure. Examining narrative evolution under specific policy contexts can therefore provide important insights into how firms interpret and respond to institutional change through disclosure practices.

In the context of China's "Dual Carbon" goal, corporate sustainability disclosure provides a particularly relevant empirical setting for examining narrative evolution. As firms adjust disclosure practices in response to new policy priorities, changes in keyword prominence, thematic structure, and semantic organization may reflect broader processes of strategic adaptation and institutional alignment. Textual analysis methods, including keyword frequency analysis, topic modeling, and semantic network analysis, offer systematic tools for examining these structural changes in corporate sustainability disclosure.

2.4 Corporate Sustainability Disclosure & Sentiment Evolution

Disclosure tone has become an increasingly important dimension in corporate communication research. While early studies of corporate reporting primarily emphasized disclosure quantity and content, subsequent research has recognized that the manner in which information is expressed carries substantial informational value. Disclosure tone reflects how firms frame their narratives, convey confidence or caution, and signal strategic positioning to external stakeholders(Henry, 2008; Loughran et al., 2011). As a result, tone constitutes a distinct analytical dimension that complements structural and thematic analyses of corporate disclosure.

In financial reporting research, disclosure tone has been examined as an indicator of managerial sentiment and strategic communication. Henry (2008), for example, finds that the tone of earnings press releases influences investor interpretation and market reaction. Similarly, Loughran et al. (2011) demonstrates that textual tone extracted from 10-K filings provides meaningful information beyond traditional quantitative financial indicators. These studies suggest that tone functions as an implicit communicative layer through which firms convey confidence, risk exposure, and strategic expectations.

In the context of sustainability disclosure, tone may serve a related yet contextually specific role. Sustainability reporting often involves forward-looking commitments,

environmental performance claims, and policy alignment statements that are difficult for external stakeholders to verify directly. As such, the tone of sustainability disclosure may signal the degree of confidence, caution, or strategic positioning embedded within environmental narratives(Cho et al., 2010; Niamh & Doris, 2007). A more optimistic tone may convey ambition and commitment, whereas a more measured tone may reflect regulatory sensitivity or awareness of implementation uncertainty.

The methodological development of sentiment analysis has provided systematic tools for measuring disclosure tone at scale. Dictionary-based approaches classify words into positive, negative, or other sentiment categories and compute aggregate tone scores based on lexical frequency(Loughran et al., 2011). These methods have been widely adopted in accounting and finance research due to their transparency and replicability(F. Li, 2010). In Chinese-language contexts, specialized sentiment dictionaries tailored to financial and corporate texts have further enabled systematic analysis of tone in sustainability disclosure.

Beyond measuring average tone levels, recent research has emphasized the dynamic evolution of disclosure tone over time. Tone evolution may reflect changes in institutional pressure, stakeholder expectations, or regulatory scrutiny. For example, studies examining environmental disclosure have found that firms adjust disclosure framing in response to legitimacy concerns and reputational risk(Cho et al., 2015). Tone shifts may therefore signal adaptation to evolving institutional environments, especially when firms face heightened accountability or policy attention.

Despite the growing literature on disclosure tone in financial reporting, comparatively fewer studies have examined tone evolution in sustainability disclosure under major national policy initiatives. In particular, limited attention has been paid to how policy-driven sustainability transitions influence the tone of corporate disclosure at the firm level. Much of the existing sentiment-based research related to environmental policy has focused on policy documents, media coverage, or public discourse, with less emphasis on firm-level sustainability reports. Consequently, the interaction between structural disclosure expansion and tonal adjustment remains underexplored in the context of climate policy transitions.

In the setting of China's "Dual Carbon" goal, corporate sustainability disclosure offers a particularly relevant context for examining sentiment evolution. As firms incorporate policy-related concepts into sustainability reporting, the tone associated with these disclosures may reflect strategic calibration under changing institutional and market expectations. Sentiment analysis provides a systematic approach to examining how disclosure tone evolves alongside structural changes in thematic emphasis and semantic

organization. By analyzing both comprehensive sentiment and policy-specific semantic window sentiment, it becomes possible to assess how corporate disclosure tone develops within broader sustainability narratives and within targeted policy contexts.

Overall, the literature suggests that disclosure tone constitutes an important dimension of corporate sustainability communication. While structural analyses capture shifts in thematic priority and conceptual organization, sentiment analysis enables examination of how firms express commitment, caution, or strategic positioning in relation to sustainability goals. Integrating structural and tonal perspectives therefore provides a more comprehensive understanding of how corporate sustainability disclosure evolves under major policy initiatives.

2.5 Research Gaps

Existing studies on China's "Dual-Carbon" goal have largely focused on policy design, regulatory frameworks, and macro-level governance mechanisms. Numerous studies apply textual analysis techniques to policy documents, such as government reports, official policy texts, and leadership speech drafts, to examine policy logic and functional mechanisms (Feng et al., 2024; B. Jiang & Raza, 2023; Zhang, 2024; Zhu et al., 2024). However, comparatively less attention has been paid to how firms, Chinese listed companies in particular, reflect and express their engagement with the "Dual Carbon" goal through their own sustainable disclosures. As corporate reports constitute an important interface between policy signals and organizational practices, the limited focus on applying textual analysis techniques to firm-level disclosure restricts our understanding of how the "Dual Carbon" goal is associated with changes in corporate sustainable narratives.

At the same time, a growing number of studies have begun to evaluate the micro-level impacts of the "Dual-Carbon" goal using firm-level data from Chinese listed companies. These studies primarily adopt economic or policy evaluation frameworks to analyze changes in financial performance, investment behavior, technological innovation, or emission efficiency(Feng et al., 2024). Corporate responses are often interpreted as efficiency-driven or incentive-based outcomes. By contrast, relatively little attention has been paid to corporate sustainability disclosure as an institutional response shaped by legitimacy-seeking behavior. The application of institutional theory to explain how the "Dual Carbon" goal is reflected in disclosure priorities and narrative structures remains limited. Therefore, existing research provides insufficient insight into why firms articulate and organize their sustainability narratives except for purely economic

interpretations.

Beyond the limited focus on firm-level sustainability disclosure, existing research has also paid relatively little attention to the structural organization of corporate disclosure narratives. Prior studies have primarily examined disclosure quantity, environmental disclosure scores, or overall disclosure levels(Clarkson et al., 2008; Hahn & Kühnen, 2013). While such approaches provide important insights into disclosure extent and content coverage, they offer limited understanding of how disclosure narratives are internally structured and organized. Corporate disclosure represents a semantic system in which concepts differ in prominence and connectivity, reflecting evolving organizational priorities and communication strategies(Cho et al., 2012). However, relatively few studies have examined how the semantic structure and centrality of climate-related concepts evolve over time, particularly in response to major policy initiatives such as China's "Dual Carbon" goal. As a result, the structural evolution of sustainability disclosure narratives at the firm level remains insufficiently explored.

In addition, although disclosure tone has been widely examined in financial reporting and corporate communication literature, its application in the context of sustainability disclosure under climate or energy policy remains limited. Prior research has demonstrated that disclosure tone reflects managerial communication strategies and conveys information about organizational positioning and credibility(F. Li, 2010; Loughran et al., 2011). Disclosure tone has been shown to play an important role in shaping stakeholder perceptions and reducing information asymmetry(Cho et al., 2012). However, most existing studies focus on financial disclosures such as earnings announcements and annual reports, with comparatively less attention given to tone evolution in sustainability disclosure under specific policy contexts. In particular, how disclosure tone associated with climate-related policy goals evolves over time at the firm level remains underexplored.

Furthermore, prior research has typically examined structural and tonal aspects of corporate disclosure separately. Structural studies focus on changes in disclosure content, keyword frequency, or thematic composition, while tone studies examine sentiment or linguistic characteristics independently(Hahn & Kühnen, 2013; Loughran et al., 2011). As a result, limited attention has been paid to the integrated evolution of disclosure structure and tone. Examining both structural prominence and disclosure tone provides a more comprehensive perspective on how firms adapt their communication strategies under changing institutional environments. Understanding this integrated evolution is particularly important in the context of major climate policy initiatives, where firms may adjust both what they disclose and how such information is communicated.

Finally, while institutional theory and signaling theory have been widely applied to explain corporate disclosure behavior, their application to the evolution of sustainability disclosure under China's "Dual Carbon" goal remains limited. Existing studies primarily rely on economic or econometric frameworks to interpret firm responses, focusing on financial performance or operational outcomes. Comparatively fewer studies adopt interpretive theoretical perspectives to examine how institutional pressure and signaling considerations are reflected in corporate disclosure narratives. Applying institutional and signaling perspectives to analyze structural and sentiment evolution in sustainability disclosure may therefore provide additional insights into how firms align their communication with evolving policy expectations.

In summary, existing research reveals several important gaps. First, firm-level sustainability disclosure under the "Dual Carbon" goal has received less attention compared to macro-level policy discourse. Following this logic, the distinction between the present study and macro-based "Dual Carbon" research does not lie in the size of the dataset, but in the analytical object and interpretive focus. Existing studies mainly examine policy mechanisms, governance structures, or economic outcomes, whereas the present study examines firm-level sustainability disclosure as a communicative response through which companies express policy alignment, thematic emphasis, and tonal adjustment. Second, the structural evolution of corporate sustainability disclosure, particularly changes in semantic centrality and narrative organization, remains insufficiently explored. Third, the evolution of disclosure tone in response to climate policy contexts has received limited investigation. Fourth, integrated analysis of structural and sentiment evolution remains underdeveloped. Finally, the application of institutional and signaling theory to interpret disclosure evolution under the "Dual Carbon" goal remains limited. Addressing these gaps provides the foundation for the present study. In addition, although computational and machine learning-based approaches have expanded the methodological scope of disclosure research in adjacent fields, comparatively less attention has been paid to the structural and sentiment evolution of firm-level sustainability disclosure under a policy-driven environment such as the "Dual Carbon" goal.

Chapter 3
Materials and Methodology

3.1 Data Collection

In recent studies, crawler technology has been widely used to scrape textual data from websites, online forums, and social platforms for research and business analysis. The website, uc.cninfo.com.cn, established in 1994, is qualified by the China Securities Regulatory Commission as the earliest professional website in China to comprehensively disclose announcements and market data for companies listed on the Shenzhen and Shanghai stock exchanges. This study applied the Python 3.12.4 programming tool to download CSR, ESG, SD and ENV reports of Chinese-listed Companies on uc.cninfo.com.cn. Specifically, targeted reports were identified by matching keywords in the dataset of uc.cninfo.com.cn, which were social responsibility, ESG, environmental report, sustainable development, governance, and management. Targeted reports were collected and aggregated as a raw dataset to cover the latest and most complete information.

This study gathered 1033, 1154, 1512, 1882 and 2279 sustainability-related disclosures of Chinese-listed companies in the period of 2019 to 2023. It should be noted that sustainability-related disclosures are typically published in the year following the reporting period in China. To further explore ownership-based heterogeneity, involved companies were categorized into state-owned enterprises (SOEs) and non-state-owned enterprises (non-SOEs) based on publicly available ownership information disclosed in corporate filings and their profiles. The final sample includes 3839 SOE disclosures and 3850 non-SOE disclosures, while 170 ones could not be matched to an ownership category due to missing or ambiguous ownership information.

This five-year window allows for a robust, panel-data comparison between the pre-policy environment (2019–2020) and the post-policy implementation stage (2021–2023), following the announcement of the Dual Carbon goal in late 2020. A total of 7860 targeted reports represent a significant expansion and more comprehensive market coverage compared to previous studies.

In all, the sample selection in this study followed several explicit principles. First, only reports disclosed through CNINFO, the official information disclosure platform for

Chinese-listed companies, were included in the dataset. Second, the sample was restricted to four major forms of sustainability-related disclosure, namely CSR, ESG, SD, and ENV reports. These report types were selected because they represent the main channels through which Chinese-listed companies communicate sustainability-related information in the public disclosure context. Third, the observation window was limited to 2019–2023 in order to support a longitudinal comparison across the pre-policy and post-policy periods surrounding the announcement of the "Dual Carbon" goal in late 2020. Fourth, to examine ownership-based heterogeneity, firms were further classified into SOEs and non-SOEs based on publicly available ownership information disclosed in corporate filings and company profiles. Reports with missing or ambiguous ownership information were retained in the full sample where applicable, but could not be included in ownership-based subgroup analysis. Finally, reports from 2024 were not included because the reporting cycle was not yet sufficiently complete at the time of data collection. Together, these principles ensured a consistent, policy-relevant, and comparable dataset for examining the structural and sentiment evolution of sustainability disclosure.

3.2 Data Preprocessing

To ensure the high quality and consistency of the text analysis, a stringent preprocessing procedure was adopted, establishing the initial framework of our prior work:

The first step was to convert all the PDF reports into plain text (.txt) format. Redundant elements such as image captions, tables, and standard boilerplate text were removed to prevent methodological noise. Subsequently, an identical step was conducted to address the mixed usage of simplified and traditional Chinese characters in the reports: the zhconv library was employed to uniformly convert all text to simplified Chinese. This step was crucial for preventing the repeated counting of core keywords due to character variations and ensuring consistency with the subsequent segmentation tool. Ultimately, the Jieba library was employed to process the texts into accurate word segmentation. A custom user dictionary, comprising the 21 core Dual Carbon and sustainability keywords, was added into Jieba to ensure these multi-character terms were treated as singular entities (e.g., "碳中和") during the analysis. Finally, a comprehensive stop-word list was applied to the corpus to remove common function words before proceeding with the LDA and Co-occurrence analyses.

3.3 Data Analysis

To address the research questions proposed in this study, four complementary text

analysis methods are applied in the data analysis process. These methods correspond to two major dimensions of disclosure evolution examined in this study, namely structural evolution and sentiment evolution. Structural evolution refers to changes in the internal organization of corporate sustainability disclosure, including changes in keyword prominence, thematic composition, and semantic centrality. Sentiment evolution refers to changes in the tone through which sustainability-related issues are communicated over time under the “Dual Carbon” goal. Based on this analytical logic, SRq1 to SRq3 examine disclosure evolution from structural perspectives, while SRq4 examines disclosure evolution from a sentiment perspective. Specifically, word frequency analysis focuses on changes in keyword prominence, topic modeling examines changes in thematic structure, co-occurrence network analysis captures changes in semantic relationships among keywords, and sentiment analysis evaluates changes in disclosure tone. Together, these methods provide a comprehensive analytical basis for examining how corporate sustainability disclosure evolved during the sample period.

3.3.1. Word Frequency Analysis & Significance Test

To quantify the change in Chinese-listed companies’ focus on the lexical level, we first selected a matrix of 21 policy-relevant keywords derived from the State Council’s "Action Plan for Carbon Dioxide Peaking Before 2030" and the “1+N” policy framework, covering key dimensions such as policy directives (e.g., Dual Carbon, Carbon Neutrality), action indicators (e.g., Carbon Emissions, Emission Reduction), and generalized sustainability terms (e.g., Green Development). The full of 21 keywords are: “Dual Carbon (双碳)”, “Carbon Neutrality (碳中和)”, “Carbon Peaking (碳达峰)”, “Carbon Tariff(碳关税)”, “CBAM”, “Carbon Border Adjustment Mechanism(碳边境调节机制)”, “Emission(排放)”, “Carbon Emissions(碳排放)”, “Emission Volume(排放量)”, “Emission Reduction (减排)”, "Environmental Policy(环境政策)”, “Policy (政策)”, “National Policy(国家政策),” “National Strategy(国家战略)”, “Environmental Governance(环境治理)”, “Environmental Protection (环境保护)”, “Environmentally Friendly (环保)”, “Green (绿色)”, “Green Development (绿色发展)”, “Sustainable Development(可持续发展)”, and "Developmental Goal（发展目标)". This method is used to address SRq1 by examining whether carbon-related keywords became more prominent in corporate sustainability disclosure following the introduction of the “Dual Carbon” goal.

Our primary metric, Document Coverage, is defined as the percentage of total reports in a given year that mention a specific keyword at least once. This metric is chosen over raw word count to effectively normalize for annual variations in sample size and report

length. To formally verify the policy's structural impact, a Two-sample Z-test for Proportions was conducted. This test compares the Document Coverage of each keyword in the baseline period (2019) against the post-policy period (2023) to determine if the observed shifts are statistically significant.

To further examine ownership-based heterogeneity, the same document coverage measures were calculated separately for SOEs and non-SOEs. This subsample analysis applies an identical keyword dictionary and measurement procedure, allowing for a descriptive comparison of disclosure patterns across ownership types.

3.3.2. Latent Dirichlet Allocation (LDA) Topic Modeling

To further understand the embedded focus beyond single keywords and capture the overall thematic structure of the corporate sustainability disclosure, we employed the LDA topic modeling technique. In a topic model, an unsupervised algorithm is applied to cluster the latent semantic structure of the set of documents and then sort out hidden topics (Papadimitriou et al., 1998). LDA is a typical topic model that calculates probability distribution and then assigns it to the topics of each document (Blei et al., 2003). Therefore, generally, LDA is employed to identify abstract themes or topics from a collection of documents. This method is used to address SRq2 by identifying how the main themes of corporate sustainability disclosure evolved over time.

In this study, the LDA analysis was performed on the entire five-year corpus to achieve two goals: (1) discover the latent topics comprising corporate sustainable discourse, and (2) track the annual topic prevalence, which is the proportion of words in the corpus assigned to each topic, to visualize the evolution of the thematic structure. Specifically, for each annual corpus, the textual data were first preprocessed through several steps, including conversion into simplified Chinese, removal of non-Chinese characters, word segmentation using the jieba tokenizer in precise mode, stop-word removal, and the exclusion of single-character tokens. After preprocessing, a dictionary was constructed for each annual corpus, and extreme terms were filtered by retaining tokens that appeared in at least two documents and in no more than 50% of the documents. The LDA model was then estimated using the gensim implementation with the following settings: number of topics=7, random state=100, update frequency=1, chunk size=100, number of passes=15, and alpha=auto. Per-word topic assignment was also enabled. Unless otherwise specified, other model parameters followed the default settings of the gensim implementation. The optimal number of topics (K) was determined using the coherence score metric, ensuring a balance between interpretability and statistical fit.

In this study, the ten keywords presented for each topic were not manually assigned,

but were selected as the top-probability words generated by the LDA model. These keywords were used to interpret the semantic meaning of each topic because they represent the most strongly associated terms within the corresponding topic distribution. The presentation of ten keywords for each topic was adopted to provide sufficient semantic information for topic interpretation while avoiding excessive noise from lower-probability words. In addition, the selection of seven topics for each annual corpus was guided not only by coherence scores, but also by cross-year interpretability. This setting allowed the model to capture the main thematic dimensions of sustainability disclosure in each year while maintaining a comparable level of semantic granularity across the observation period. Beyond identifying the content of each theme, we calculated the Topic Prevalence for each lineage across the five years. Topic prevalence is defined as the expected proportion of a document (or the entire annual corpus) dedicated to a specific topic. To estimate annual topic prevalence, the topic distribution of each document was obtained using the trained LDA model with full topic probabilities retained for all topics. The prevalence of each topic in a given year was then calculated as the average topic probability across all documents in the annual corpus. These annual topic-level values were subsequently used for semantic alignment and lineage-level comparison across years. By aggregating the prevalence of annual topics belonging to the same semantic lineage, we quantified the changes in different sustainability themes. This allows us to systematically examine changes in the relative prominence of different sustainability narrative dimensions in corporate disclosure.

3.3.3. Co-occurrence Network Analysis

As the last step of structural analysis, we utilized co-occurrence network analysis (Callon et al., 1983) to investigate changes in the relational structure of the corporate narrative from the perspective of sustainability reporting. This method examines the relational structure between the 19 core keywords concluded from Word Frequency and LDA analyses, where a link between two keywords is established if they appear within the same sentence or paragraph. This method is used to address SRq3 by examining how the structural positions and semantic connections of core keywords changed over time.

The network analysis was performed separately for the pre-policy baseline year (2019) and the final year (2023). To quantifiably describe the structural features of the co-occurrence networks, three indicators were applied. Network Density indicates the proportion of realized co-occurrence links among all possible links within the selected keyword set (Wasserman, 1994). Degree centrality presents the number of times a given keyword co-occurs with other selected keywords, which illustrates the breadth of its

semantic connections(Freeman, 1978). Weighted degree measures the total frequency of co-occurrence between a keyword and all its connected keywords, which identifies the intensity of its involvement in the overall narrative. Because the number of sample disclosures differs between 2019 and 2023 (1033 vs. 2279), the weighted degree was normalized to ensure comparability across years. Specifically, the raw weighted degree of each keyword was divided by the total number of reports in the corresponding year and multiplied by 100. Finally, the topological changes in semantic associations were visualized to facilitate comparison in the two co-occurrence networks.

In the visualized network, each node represents a selected keyword, and each edge represents a realized co-occurrence relationship between two keywords within the same sentence or paragraph. The size of a node reflects its degree centrality, indicating how broadly a keyword is connected with other selected keywords in the network. By combining node-level indicators with network density, the analysis allows both local and overall structural changes to be interpreted in a consistent manner. Therefore, the centrality of a keyword in this study was identified through both quantitative indicators and visual network structure. A keyword was interpreted as becoming more central when it showed an increase in degree centrality, indicating broader semantic connections with other selected keywords, and an increase in normalized weighted degree, indicating stronger co-occurrence intensity after adjusting for differences in the number of annual reports. In the visualized network, this change was also reflected by a larger node size and a more connected position within the network. In this way, the co-occurrence analysis can be applied to evaluate whether “Dual Carbon” related concepts became structurally central in corporate sustainability disclosure, through combining visual network patterns with measurable indicators.

3.3.4. Sentiment Analysis

Sentiment analysis, also referred to as opinion mining, is a text analysis technique used to identify and quantify evaluative orientation expressed in textual data(N. Li & Wu, 2010; Sun et al., 2023). Originally developed within computational linguistics and information science, sentiment analysis has been widely applied in social media research, public opinion monitoring, and financial communication studies. In the context of corporate disclosure research, sentiment analysis provides a systematic approach to examining the tone and evaluative stance embedded in narrative texts.

Unlike traditional word frequency analysis that captures thematic attention, sentiment analysis focuses on the emotional polarity or evaluative direction of language use. Prior research has demonstrated that disclosure tone may reflect managerial confidence,

impression management strategies, or efforts to shape stakeholder perception(Henry, 2008; Loughran et al., 2011). Particularly in sustainability and environmental disclosure studies, sentiment analysis has been employed to assess whether firms adopt overly optimistic language, defensive rhetoric, or more measured communication strategies when addressing environmental commitments and regulatory expectations(Cho et al., 2015; F. Li, 2010).

Methodologically, sentiment analysis can be conducted using machine learning approaches or lexicon-based approaches. Given the interpretive objective of this study and the large-scale corpus of sustainability reports, a lexicon-based approach is adopted. Lexicon-based methods rely on predefined dictionaries that classify words into positive and negative categories and compute sentiment scores based on their relative frequency within a given text (Liu, 2012; Loughran & McDonald, 2011). This approach offers transparency and interpretability, which is particularly important when analyzing policy-related corporate disclosure.

To capture tone evolution under the "Dual Carbon" goal, this study applies sentiment analysis at two levels. First, comprehensive document-level sentiment scores are calculated to reflect the overall tone of sustainability disclosure. Second, a policy-focused semantic window is constructed based on core "Dual Carbon" keywords identified from authoritative policy documents. Sentiment scores within this semantic window provide a more targeted assessment of tone specifically associated with carbon-related disclosure. This dual-level design allows for a structured comparison between general disclosure tone and policy-specific tone.

Importantly, the sentiment analysis in this study does not seek to infer managerial intention or causal impact. Instead, it provides an interpretive lens for examining how the evaluative framing of sustainability disclosure evolves alongside structural changes in thematic attention and semantic centrality.

To enable policy-specific sentiment and attention analysis, a dedicated "Dual Carbon" keyword dictionary was constructed based on the central policy documents of China's "1+N" policy framework, namely the Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy (hereafter referred to as the "Guidance") and the Action Plan for Carbon Dioxide Peaking Before 2030 (hereafter referred to as the "Plan"). These two policy documents represent the foundational policy framework outlining the core objectives, implementation pathways, and governance priorities of the "Dual Carbon" goal and serve as the primary reference for subsequent supporting policies. To identify representative policy-related terminology, word frequency analysis was first conducted on the full text

of the Guidance and Plan. High-frequency terms directly associated with carbon mitigation, emission management, and energy transition were identified and further refined through manual screening to ensure policy relevance and semantic clarity. Based on this procedure, a “Dual Carbon” keyword dictionary consisting of sixteen predefined terms was established. These keywords capture the core policy dimensions of carbon peaking, carbon neutrality, emission reduction, and energy transition, and provide a consistent vocabulary basis for the subsequent normalized keyword frequency analysis and semantic window–based sentiment analysis.

To quantify corporate attention toward the “Dual Carbon” goal policy narratives, the normalized keyword frequency was employed as the primary measurement indicator. This metric is defined as the total number of occurrences of the predefined “Dual Carbon” keywords within a disclosure document, divided by the total number of words in the document, and multiplied by 10000. Specifically, the occurrence frequencies of all sixteen “Dual Carbon” keywords were aggregated to form a composite indicator representing the overall intensity of “Dual Carbon” related terminology within each disclosure. This normalization procedure ensures comparability across reports of varying lengths and allows for consistent cross-year and cross-group analysis. Compared to raw keyword counts, the aggregated normalized keyword frequency provides a more reliable measure of the relative prominence of “Dual Carbon” attention within corporate sustainability disclosures. This indicator was calculated at the document level and subsequently aggregated at the annual level to examine temporal trends, as well as across ownership categories to enable comparative analysis between state-owned enterprises and non-state-owned enterprises.

The semantic window extraction method was employed to capture sentiment specifically associated with Dual Carbon–related narratives. For each occurrence of a predefined Dual Carbon keyword, a contextual text segment consisting of 75 words before and 75 words after the keyword was extracted from the disclosure document. Specifically, a stratified sample of 100 disclosure documents across the observation period was analyzed to examine sentence length characteristics. This window size was determined based on empirical analysis of sentence length distributions. As shown in Figure 3, the median sentence length is approximately 60 characters and the mean sentence length is approximately 95 characters, indicating that the selected window size is sufficient to capture complete semantic units while minimizing the inclusion of unrelated content. This semantic window extraction procedure allows for more precise measurement of sentiment directly associated with Dual Carbon–related disclosure narratives.

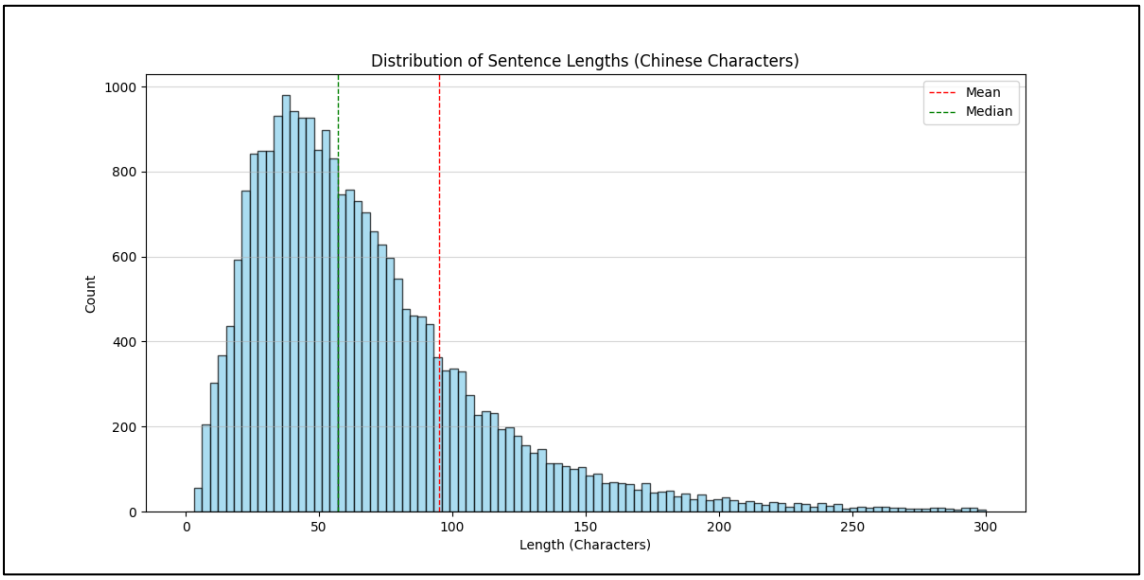

Figure 3: Distribution of Sentence Lengths in Sustainability Disclosure Documents

Sentiment scoring was conducted using the Chinese financial sentiment lexicon developed by (F. Jiang et al., 2019), which has been widely applied in corporate disclosure and financial text analysis. Each extracted text segment was first processed using Chinese word segmentation to identify individual tokens. These tokens were then matched against the sentiment lexicon to classify words as positive, negative, or neutral. The sentiment score for each text segment was calculated using the following formula:

$$Score = \frac{Pos - Neg}{Pos + Neg + 1}$$

where Pos and Neg represent the number of positive and negative words identified within the text segment. The addition of 1 in the denominator serves as a smoothing factor to avoid division by zero. Under this formulation, higher values indicate a more positive disclosure tone, while lower values indicate a more moderated or less strongly positive tone. Although negative values are theoretically possible, sustainability disclosure in the present corpus is generally characterized by a predominantly positive communicative style. For this reason, the analytical emphasis of the study is placed on variation and directional change in sentiment over time, instead of treating the task as a binary classification of positive versus negative disclosure. In addition to sentiment scores, the proportions of positive and negative words relative to the total number of words were also calculated to provide supplementary indicators of sentiment composition.

To improve the robustness of sentiment analysis results, several data cleaning procedures were applied. First, text segments containing fewer than ten valid words after segmentation were excluded to ensure sufficient information for reliable sentiment evaluation. Second, winsorization was applied at the 1st and 99th percentiles to reduce

the influence of extreme values. Winsorization limits the effect of outliers while preserving the overall distribution characteristics of the data. These procedures were applied consistently across the observed years and ownership groups to ensure comparability of semantic windows based sentiment analysis results.

(AI-assisted tools were used only for language editing and proofreading and did not contribute to the research design, data analysis, or interpretation of results).

3.4 Summary

This chapter presented the research design and methodological framework adopted in this study to examine the structural and sentiment evolution of corporate sustainability disclosure under the "Dual Carbon" goal. The chapter first described the data sources and sample selection process, focusing on sustainability-related reports published by Chinese-listed companies from 2019 to 2023. Preprocessing procedures, including text cleaning, tokenization, and keyword identification, were implemented to ensure the reliability and consistency of textual analysis.

To investigate structural evolution, three complementary analytical approaches were employed. Keyword frequency analysis was used to assess changes in thematic attention. Topic modeling based on Latent Dirichlet Allocation (LDA) was applied to identify thematic structures and trace their evolution over time. Co-occurrence network analysis was conducted to examine semantic relationships among keywords and to evaluate changes in structural centrality and connectivity within disclosure narratives.

To examine sentiment evolution, lexicon-based sentiment analysis was implemented at both the document level and the policy-specific semantic window level. The construction of a "Dual Carbon" semantic window enabled a focused evaluation of tone associated with carbon-related disclosure. In addition, ownership-based heterogeneity analysis was conducted to explore differences in disclosure tone between SOEs and non-SOEs.

To conclude, the analytical methods applied in this study clarify how disclosure evolution is examined from integrated structural and sentiment dimensions. In this study, disclosure structure refers to the overall information organization within corporate disclosure, including the prominence of the "Dual Carbon" related keywords, the thematic composition of disclosure content, and the semantic centrality of core concepts within the disclosure network. These dimensions reflect how sustainability-related issues are prioritized, organized, and connected in the corporate narrative. On the other hand, sentiment analysis captures how such issues are evaluatively expressed and framed over time under the "Dual Carbon" goal. In this sense, the analytical framework of this study understands corporate sustainability disclosure as a multidimensional system composed

of structural organization and expressive tone.

Based on this conceptualization, it is important to distinguish between changes and evolution. In this study, changes refer to observable differences in specific analytical dimensions across years, such as shifts in keyword prominence, thematic prevalence, semantic centrality, or disclosure tone. Evolution refers to the cumulative and directional trajectory formed by these sequential changes across the sample period. From this perspective, the evolution of corporate sustainability disclosure can be conceptually expressed as the joint development of structural evolution and sentiment evolution over time, where structural evolution is reflected in changes in keyword prominence, thematic composition, and semantic centrality, and sentiment evolution is reflected in changes in disclosure tone. This conceptualization can be further summarized in a compact form:

$$Disclosure = Structure + Sentiment$$

Where,

$$Structure = Narrative\ Priority + Narrative\ Logic + Semantic\ Composition$$

$$Change_t = Disclosure_t - Disclosure_{t-1}$$

$$Evolution = Trajectory(Change_1, Change_2, \ldots, Change_n)$$

Where,

$Disclosure_t$ refers to the state of a specific disclosure dimension at time t, such as keyword prominence, thematic composition, semantic centrality, or disclosure tone.

Therefore, in this formulation, corporate sustainability disclosure is understood as the combination of structure and sentiment; Changes represent observable differences between time points, while evolution refers to the broader longitudinal pattern formed by the accumulation and direction of these sequential changes across the sample period. Accordingly, the evolution of corporate sustainability disclosure in this study is understood as the longitudinal trajectory formed by sequential changes in structural and sentiment dimensions over the period from 2019 to 2023. This conceptual distinction provides the basis for interpreting the empirical findings of this study in a coherent and integrated manner.

Through the integration of structural and sentiment analysis methods, this chapter established a comprehensive analytical framework for examining how corporate sustainability disclosure evolved under the “Dual Carbon” policy context. The analytical relationships among the four methods, the corresponding research questions, and the two major dimensions of disclosure evolution are summarized in Figure 4. The methodological framework developed in this chapter provides the empirical basis for the

results presented in Chapter 4 and the interpretive analysis discussed in Chapter 5.

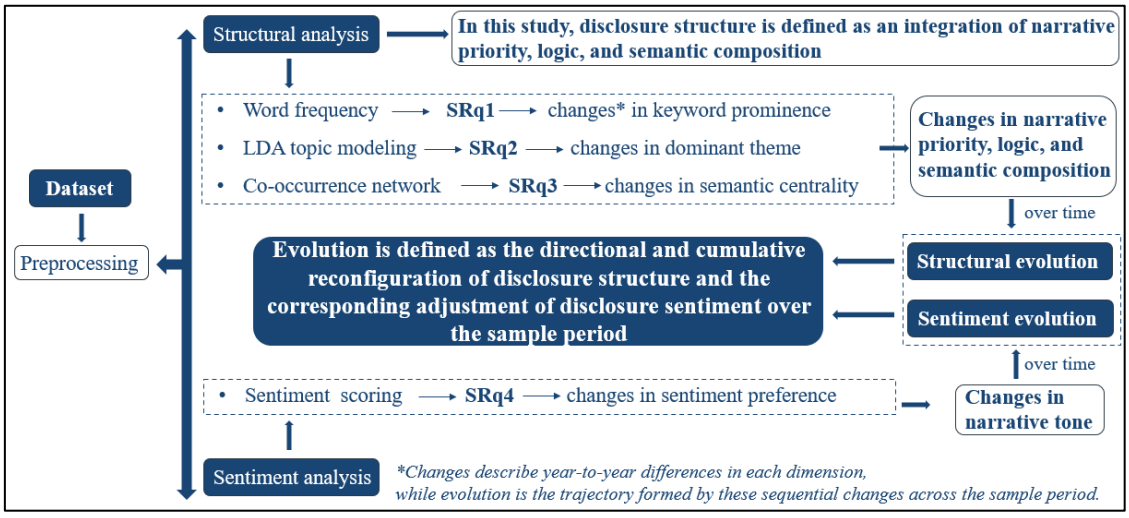

Figure 4: Analytical dimensions of disclosure evolution and corresponding methods

It should also be clarified that this study adopts a large-scale computational text analysis approach instead of a qualitative close reading of every individual report. The purpose of this methodological design is to systematically capture aggregated disclosure-level patterns across 7,860 sustainability-related reports. Therefore, the findings of this study should be interpreted as evidence of disclosure narratives and communication patterns, rather than as direct verification of firms' actual carbon-reduction performance or environmental outcomes. To strengthen the reliability of the analysis, this study used reports collected from the official disclosure platform, applied consistent preprocessing procedures, and combined multiple complementary methods to examine different dimensions of disclosure evolution. Keyword analysis captures changes in narrative priority, LDA topic modeling identifies thematic organization, co-occurrence network analysis examines semantic composition, and sentiment analysis evaluates disclosure tone. In this sense, the integrated framework is designed not as a simple combination of methods, but as a multidimensional analytical strategy for examining structural and sentiment evolution in corporate sustainability disclosure.

Chapter 4
Results

4.1 Changes in Keyword Coverage

4.1.1. Comprehensive-Level Changes in Keyword Coverage

To describe changes in keyword coverage over time, we analyze the document coverage of 21 targeted keywords from 2019 to 2023. The statistical significance of these changes is assessed using a two-sample Z-test for Proportions (see Table 1), comparing the pre-policy baseline (2019) with the latest post-policy period (2023).

Table 1 Keyword Document Coverage by year

Keywords	2019	2020	2021	2022	2023	z-test for 2023 to 2019
Dual Carbon	0.00%	1.39%	44.11%	60.15%	65.69%	$p < 0.001$
Carbon Neutrality	0.68%	24.26%	52.18%	57.86%	59.59%	$p < 0.001$
Carbon Peaking	0.00%	16.20%	46.10%	50.69%	51.38%	$p < 0.001$
Carbon Tariff	0.00%	0.00%	0.13%	0.69%	2.06%	$p < 0.001$
CBAM/Carbon Border Adjustment Mechanism	0.00%	0.00%	0.00%	0.37%	0.88%	$p = 0.002$
Emission	69.60%	72.18%	76.39%	83.00%	86.53%	$p < 0.001$
Carbon Emissions	16.65%	23.57%	43.52%	54.20%	65.99%	$p < 0.001$
Emission Volume	32.43%	34.40%	44.25%	53.29%	63.45%	$p < 0.001$
Emission Reduction	72.22%	74.52%	78.77%	83.21%	85.56%	$p < 0.001$
Environmental Policy	3.00%	2.51%	3.17%	4.25%	4.43%	$p = 0.051$
Policy	87.51%	88.82%	89.75%	91.71%	93.07%	$p < 0.001$
National Policy	15.00%	18.54%	22.16%	24.87%	30.01%	$p < 0.001$
National Strategy	18.01%	20.10%	25.20%	29.01%	36.02%	$p < 0.001$
Environmental Governance	15.00%	16.46%	17.33%	20.78%	23.69%	$p < 0.001$
Environmental Protection	85.67%	86.14%	87.76%	89.85%	92.72%	$p < 0.001$
Environmentally Friendly	93.71%	92.63%	93.45%	96.12%	95.61%	$p = 0.020$
Green	85.58%	85.79%	89.42%	93.15%	93.86%	$p < 0.001$
Green Development	49.66%	53.64%	62.83%	69.98%	77.36%	$p < 0.001$
Sustainable Development	91.38%	91.59%	91.87%	94.74%	95.30%	$p < 0.001$
Developmental Goal	24.10%	27.90%	28.37%	30.77%	37.17%	$p < 0.001$

A noticeable growth is observed in keywords directly related to the national “Dual Carbon” strategy. The term “Dual carbon” exhibited a document coverage of 0.00% in

2019 but surged to 65.69% in 2023. Similarly, “Carbon Neutrality” and “Carbon Peaking” experienced rapid increases, reaching 59.59% and 51.38%, respectively. The Z-test results ($p < 0.001$) confirm that these changes are statistically significant, which indicates a substantial expansion in the presence of policy-related climate terms in corporate sustainability disclosures.

Apart from these policy-specific terms, the results also show prominence growth of other categories of keywords within corporate sustainability disclosures. Broad and long-established terms such as “Environmental Protection” remained consistently high, increasing moderately from 85.67% to 92.72%. At the same time, action-oriented and measurement-focused terms expanded substantially. For instance, “Carbon Emissions” and “Emission Volume” rose from 16.65% and 32.43% in 2019 to 65.99% and 63.45% in 2023, respectively ($p < 0.001$).

In contrast, universal sustainability concepts such as “Sustainable Development” already exhibited a high baseline coverage in 2019 (91.38%) and continued to increase slightly to 95.30% in 2023 ($p < 0.001$), which indicated a sustained trend. Specifically, these changes in keyword coverage were continually followed by existing sustainability concepts, instead of being replaced by policy-specific terms.

To capture corporate attention toward emerging international climate trade mechanisms, the technical abbreviation “CBAM” and its formal term “Carbon Border Adjustment Mechanism” were jointly examined. While neither term appeared in the 2019 baseline, the combined indicator reached a document coverage of 0.88% in 2023 ($p = 0.002$). Together with the rise of “Carbon Tariff” (0.00% to 2.06%, $p < 0.001$). These results indicate the emergence of explicit references to external carbon border adjustment and carbon tariffs in corporate sustainability disclosures.

4.1.2. Ownership-Based Differences in Disclosure Patterns

To explore organizational heterogeneity in corporate sustainability disclosure under the “Dual-Carbon” goal, we further examine keyword document coverage patterns by ownership type, which distinguishes between SOEs and non-non-SOEs. Through the same 21 targeted keywords and word frequency analysis, annual keyword document coverage is calculated separately for the two subsamples over the period 2019-2023.

Consistent with the comprehensive trends, both SOEs and non-SOEs exhibited a rapid increase in keywords directly related to the national “Dual Carbon” strategy. However, SOEs displayed a sharper and more substantial increase among these keywords (see Figure 5). From 2019 to 2023, the document coverages of “Dual Carbon,” “Carbon

Neutrality," and "Carbon Peaking" in SOEs sustainable disclosures grew from 0.00%, 0.54%, and 0.00% to 75.12%, 67.19%, and 62.81%, respectively. Over the same period, the corresponding rates among non-SOEs rose to 57.01%, 52.62%, and 41.10%, remaining consistently below the SOEs level.

Focusing on the post-policy implementation stage in 2023, SOEs saw higher document coverage than the overall sample across nearly all targeted keywords, while non-SOEs generally fell below the comprehensive performance. The largest gap of document coverage was observed for "National Strategy", which was 51.07% of SOEs' sustainable disclosures, compared with 36.02% in the comprehensive performance and only 21.67% among non-SOEs. In contrast, the document coverages of "Environmental Policy" and "Sustainable Development" experienced higher figures among non-SOEs.

Besides, universal sustainability concepts such as "Environmental Protection", "Environmentally Friendly", "Green", and "Sustainable Development" were consistently seen with high document coverages throughout the whole study period across the comprehensive performance, SOEs and non-SOEs sustainable disclosures. For these broadly defined sustainability terms, differences in ownership-based disclosure patterns appeared relatively modest.

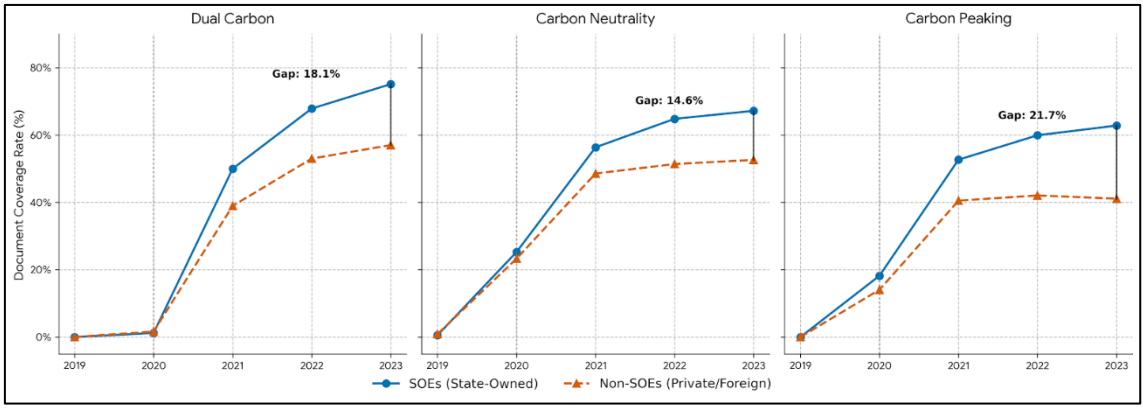

Figure 5: Document Coverage of Selected Keywords: SOEs vs. Non-SOEs

4.2 Evolution of Corporate Sustainability Disclosure Topics

4.2.1. Thematic Identification and Definition

Before topic interpretation, the optimal number of topics for each year was determined using coherence score analysis across a range of K (2 to 11) values (see Figure 6). While lower values of K exhibited slightly higher cross-year stability, K = 7 was selected to

balance semantic granularity and interpretability within each year's sustainable disclosures.

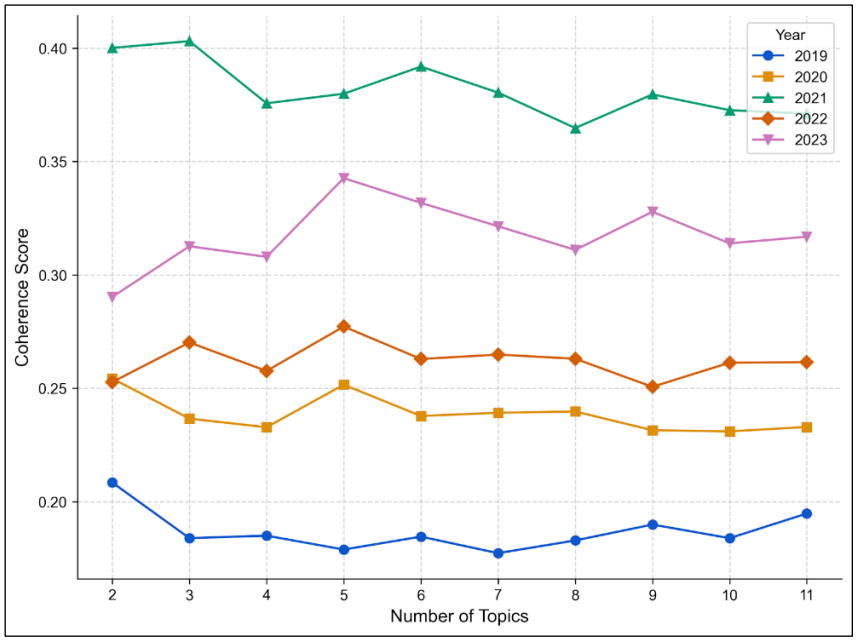

Figure 6: Coherence score from 2019 to 2023

Adopting the optimal topic number k = 7 and individually modeling each year's sustainable disclosures from 2019 to 2023, a total of 35 latent topics (7 topics per year) was generated. To enhance interpretability and enable cross-year comparison, these topics were categorized based on the semantic similarity of their high probability keywords and dominant thematic content. Consequently, five recurrent thematic lineages were identified, which collectively represent recurring thematic patterns in corporate sustainability narratives in China. These five lineages are: Climate & Emission Strategy, Clean Energy & Technical Upgrades, Green Finance & Risk Control, Resource Utilization & Pollution Control, and Medical & Bio-safety.

Table 2 presents the mapping between the annual topic indices and the corresponding thematic lineages. Figure 7 shows the annual prevalence of these lineages in the form of a stacked area chart, visualizing corporate sustainability disclosure structural evolution at the macro-level. This visualization presents changes in the relative prevalence of thematic lineages over time, showing an expansion of climate-oriented themes together with a gradual rebalancing of traditional pollution-related narratives.

It should be noticed that a limited number of topics exhibiting high year-specific heterogeneity (e.g., niche sectoral events) were excluded from these core lineages to ensure analytical focus on the structural shifts associated with the "Dual-Carbon" goal. This classification framework provides the basis for the following detailed analysis of

content evolution and prevalence trends.

Table 2 Mapping of Annual Topics to Semantic Lineages

Lineage	2019	2020	2021	2022	2023
Climate & Emission Strategy	T1: Governance, Waste, GHG	T2: Governance, GHG, Climate Change	T5: Governance, Issues, Info Security	T0: Governance, GHG, Climate Change	T2: Governance, Chemicals, Climate
Clean Energy & Technical Upgrades	T6: Automotive, New Energy, Factory	T1: Power, Gas, Construction	T1: Power, Generation, Nuclear	T1: Wind Power, Generation, Equipment	T3: Wind Power, Energy Storage, Natural Gas
Green Finance & Risk Control	T0: Financial Services, Insurance, AML	T3: Financial Services, Insurance, SMEs	T3: Green Finance, AML, Insurance	T3: Green Finance, Cybersecurity, Data Security	T5: Green Finance, Cybersecurity, Data Security
Resource Utilization & Pollution Control	T4: Wastewater, Exhaust Gas, Mining Area	T5: Mining, Coal, Chemical Industry	T0: New Materials, Coal, Sewage	NA	T1: Mining, Steel, Metals
Medical & Biosafety	T3: Medical Science, Hospital, Medicine	T6: Biological, Medicine, Vaccine	T4: Biological, Drug, Vaccine	T2: Biological, Medicine, Drug	T6: Medicine, Drug, Patient

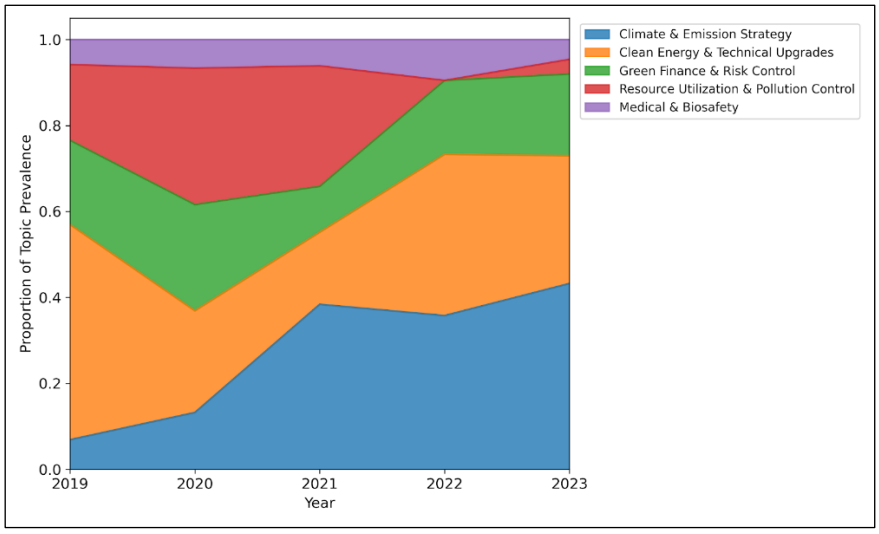

Figure 7: Lineages Prevalence from 2019 to 2023

4.2.2. Lineage 1: Climate & Emission Strategy

From the perspective of Topic evolution, the “Climate & Emission Strategy” lineage shows a clear structural evolution in disclosure content across the sample period (see

Figure 8). Specifically, terms such as “governance (管治)”, “greenhouse gases (温室气体)”, “emission volume (排放量)”, and “labor rights (劳工)” consistently appeared as high-probability keywords, forming a stable institutional backbone of this theme. Conversely, obvious shifts were seen in the composition of the rest of the topic terms. The term “waste (废弃物)”, which was prominent in 2019 and 2020, disappeared from this lineage after 2021. Beginning in 2020, climate-specific terminology such as “climate change (气候变化)” increased markedly in probability. After 2021, the topic further incorporated sector-related and technology-related terms, including “photovoltaics(光伏)”, “electric(电动)”, “automotive (汽车)”, “chips (芯片)”, and “chemicals (化学品)”. Additionally, the term “privacy (隐私)” was observed frequently in 2021 and 2022, indicating corporate concerns related to data became increasingly associated with sustainable disclosure during this period.

From the perspective of Annual prevalence evolution, Lineage 1 presents the largest increase among all identified themes. Its topic annual prevalence rose sharply from 0.0593 in 2019 to 0.3458 in 2023 (see Figure 9), suggesting a growth of nearly six times in narrative weight. A considerable expansion of lineage 1 prevalence was first observed between 2020 and 2021, which rose from 0.0682 to 0.1826, and it aligned with the post-announcement phase of China’s “Dual-Carbon” goal. This notable and rapid growth indicates issues related to climate and emissions switched from a marginal position to a central component of corporate sustainability reporting over the study period.

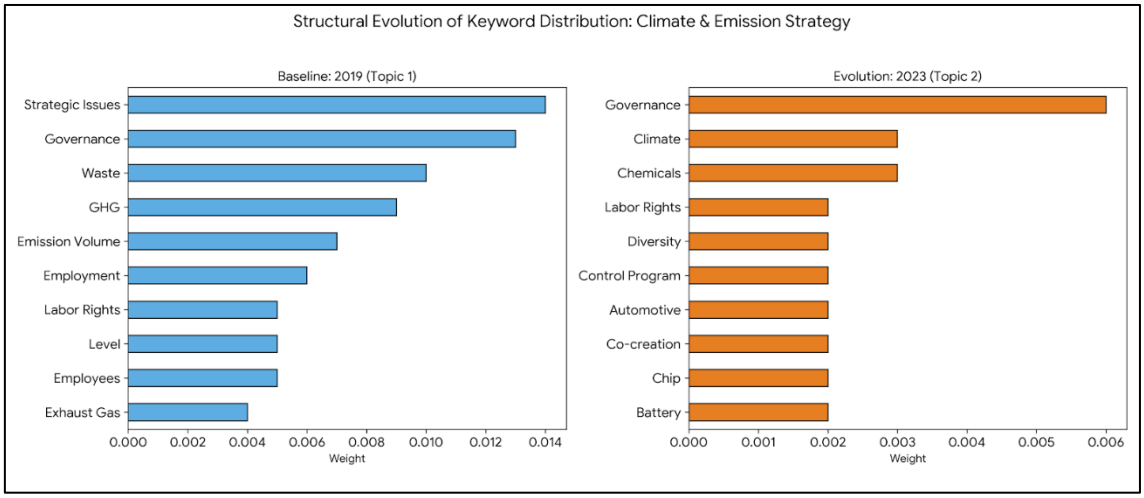

Figure 8: Structural Evolution of Keywords Distribution: Climate & Emission Strategy (2019 vs. 2023)

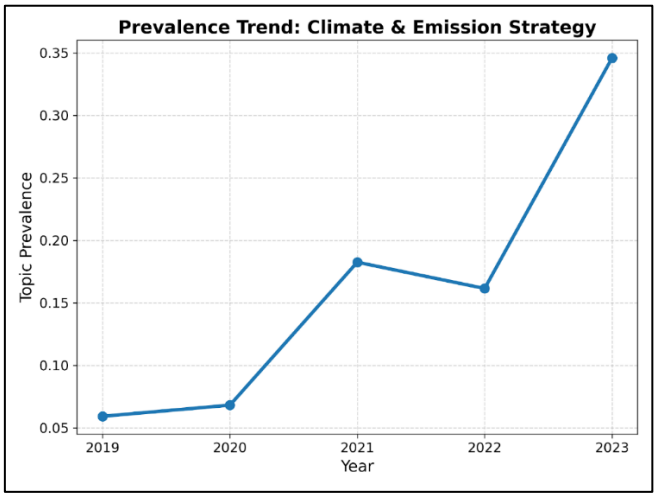

Figure 9: Prevalence Trend: Climate & Emission Strategy (from 2019 to 2023)

4.2.3. Lineage 2: Energy & Technical Upgrades

From the perspective of topic evolution, lineage 2 Clean Energy & Technical Upgrades displays a moderately wide-distributed structure, mainly involving sectors of energy systems, equipment, and transportation (see Figure 10). Compared with other lineages, its high-probability keywords are distributed across multiple sectoral and technical domains rather than concentrated on a single category or concept. Apparent changes in the composition of high probability keywords can be seen over time. In 2019, the term "new energy (新能源)" first appeared as a representative broad concept within this lineage and was subsequently followed by the appearance of more detailed terms in the following period. From 2020 onward, terms related to power systems, such as "power (电力)" and "power generation (发电)", became consistently prominent. After 2021, more specific energy technologies, including "wind power (风电)", "photovoltaics (光伏)", "nuclear power (核电)", and "power generation (发电)", appeared with increased probabilities. Additionally, the term "governance (管治)" emerged as the highest probability keyword in 2021. This was followed in 2023 by the appearance of terms such as "youth (青年)", "SASAC (国资委)", "governance (管治)", and "rectification (整治)", reflecting that lineage 2 tended to cover terms or concepts related to organizational or administrative respects.

From the perspective of annual prevalence evolution, the "Clean Energy & Technical Upgrades" lineage experienced a significant decline followed by a partial recovery over the study period (see Figure 11). In detail, its topic prevalence decreased from 0.4307 in 2019 to a dramatically lower score of 0.0797 in 2021, but rebounded to 0.2376 in 2023. Overall, this trend reflects a substantial reduction in the relative narrative weight of this

lineage compared with its initial prominence in 2019.

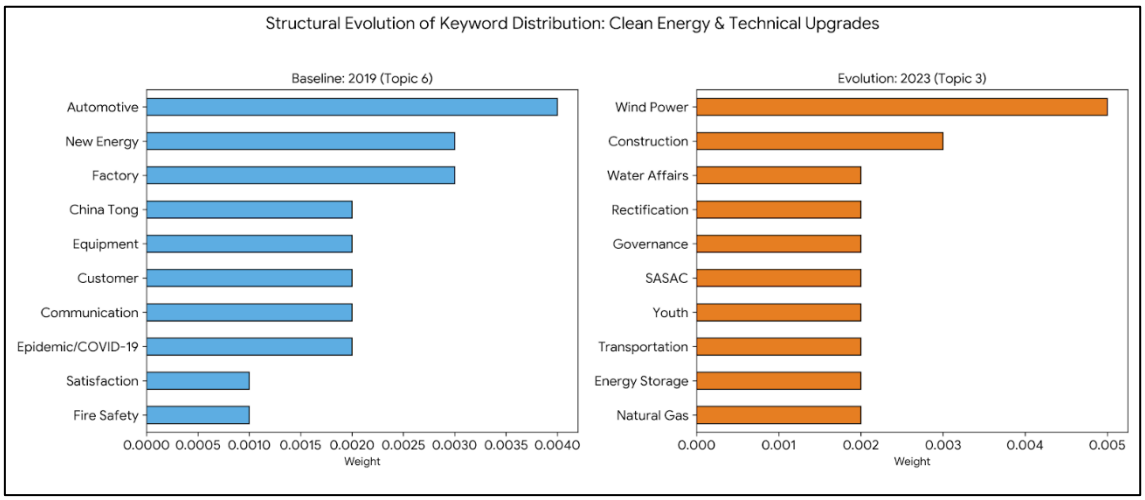

Figure 10: Structural Evolution of Keywords Distribution: Clear Energy & Technical Upgrades (2019 vs 2023)

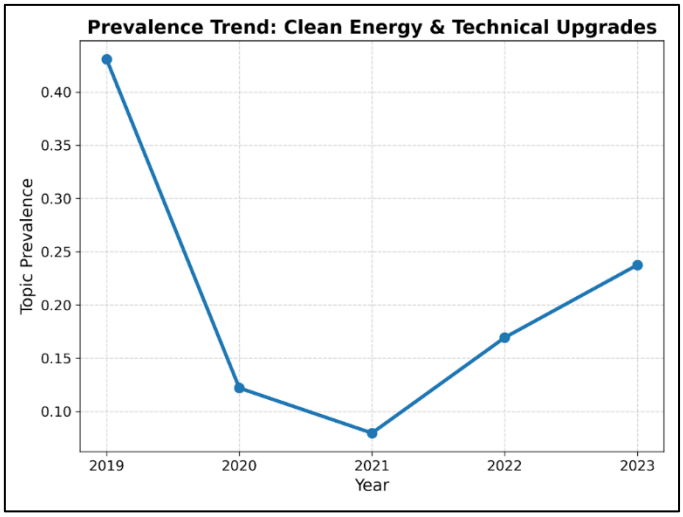

Figure 11: Prevalence Trend: Clear Energy & Technical Upgrades (from 2019 to 2023)

4.2.4. Lineage 3: Green Finance & Risk Control

From the perspective of topic evolution, the "Green Finance & Risk Control" lineage exhibits a high degree of semantic stability over the sample period (see Figure 12). Terms such as "financial services (金融服务)," "green finance (绿色金融)," and "insurance (保险)" consistently appeared as high-probability keywords from 2019 to 2023, forming the core vocabulary of this theme. Several recurrent features further characterize this topic. The term "anti-money laundering (反洗钱)" appeared occasionally in 2019, 2021, and 2023, indicating the financial regulatory dimension embedded in this lineage. In addition,

socially oriented financial terms including “small and micro enterprises (小微),” “inclusive finance (普惠),” and “rural areas (乡村)” were consistently seen from 2019 to 2023, demonstrating the continued presence of vocabulary related to corporate social responsibility. This lineage experienced an obvious shift as well in the technological dimension. The generalized term “digitalization (数字化)” was first observed in 2020 and subsequently expanded into a more specific set of keywords related to digital technology, including “cybersecurity (网络安全),” “data security (数据安全),” “software (软件),” “models (模型),” and “information technology (信息技术)” in 2022 and 2023.

From the perspective of annual prevalence evolution, lineage 3 “Green Finance & Risk Control” possesses a fluctuating pattern with an overall recovery trend over the study period (see Figure 13). Its topic prevalence declined from 0.1689 in 2019 to its lowest level of 0.0508 in 2021 and then bound back to 0.1523 in 2023. This U-shaped trajectory indicates that while the relative narrative weight of this lineage temporarily decreased, it regained prominence toward the end of the sample period.

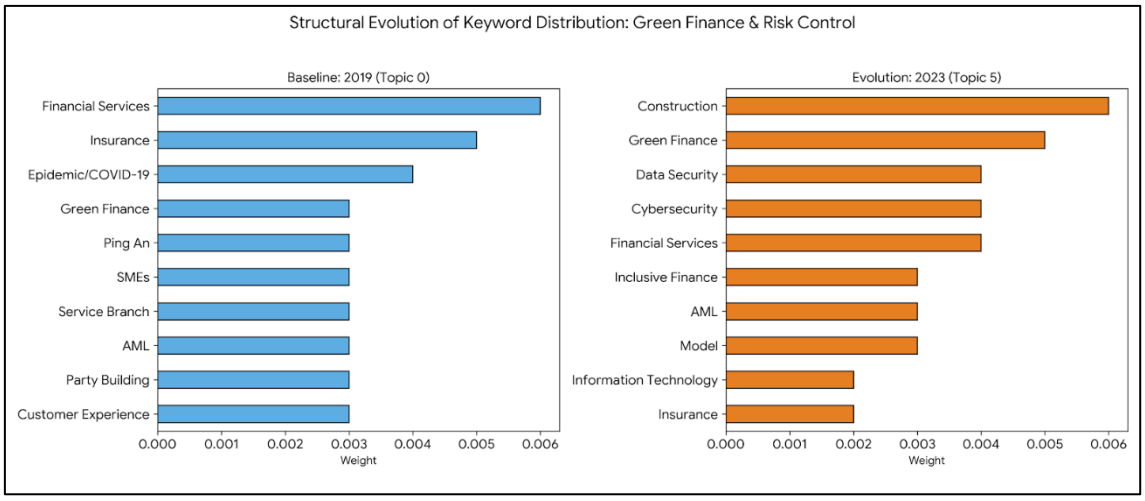

Figure 12:Structural Evolution of Keywords Distribution: Green Finance & Risk Control (2019 vs 2023)

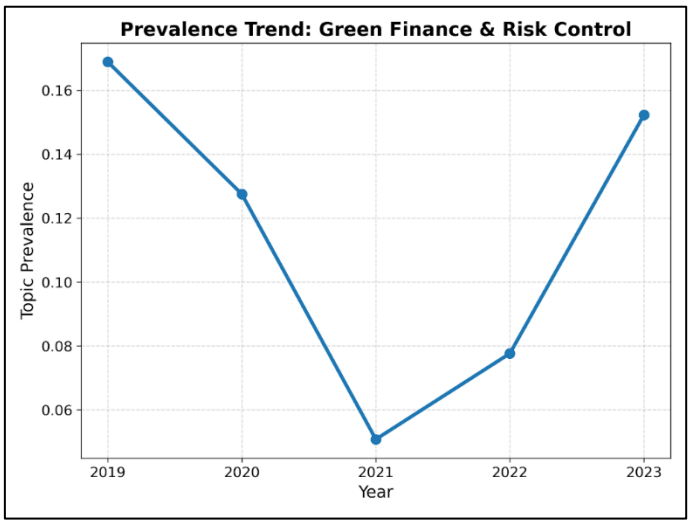

Figure 13: Prevalence Trend: Green Finance & Risk Control (from 2019 to 2023)

4.2.5. Lineage 4: Resource Utilization & Pollution Control

From the perspective of topic evolution, lineage 4 Resource Utilization & Pollution Control presents the highest degree of structural instability among all identified themes (see Figure 14). The topic of 2019 in this lineage was basically featured by terms reacting to pollution, which were, but not limited to, "wastewater (废水)," "exhaust gas (废气)," and "prevention and control (防治)." To further understand it, a high probability keywords distribution like this indicates a focus on end-of-pipe environmental management. Across the study period, keywords related to traditional resource-intensive and high-pollution industries, such as "mining areas (矿区)," "coal (煤炭)," "chemical industry (化工)," "steel (钢铁)," and "metals (金属)", emerged recurrently, which suggest a persistent association of lineage 4 with heavy industrial activities.

However, the internal composition of this lineage did not indicate a stable or cumulative evolution. In 2021, the topic temporarily incorporated terms such as "new materials (新材料)," "new energy (新能源)," "occupational diseases (职业病)," and "hazards (危险)," which reflected a broadened response to pollution-related risks. To be noticed, there were no identified topics possessing sufficient semantic coherence to be consistently mapped into this lineage in 2022. Therefore, it was observed that a dominant theme, resource utilization or pollution control, was missing in that year. By 2023, the remaining terms associated with this lineage mainly focused on industrial materials and components, such as "steel (钢铁)," "metals (金属)," and "components (零部件)," indicating a narrowed and residual form of discourse.

From the perspective of annual prevalence evolution, "Resource Utilization & Pollution Control" lineage shows a significant and continuous decline over the study

period (see Figure 15). Its topic prevalence decreased sharply from 0.1515 in 2019 to 0.0272 in 2023, which was the most substantial reduction among all five lineages. Despite minor fluctuations in ongoing years, the overall trend indicates a rapid marginalization of this theme within corporate sustainability disclosures.

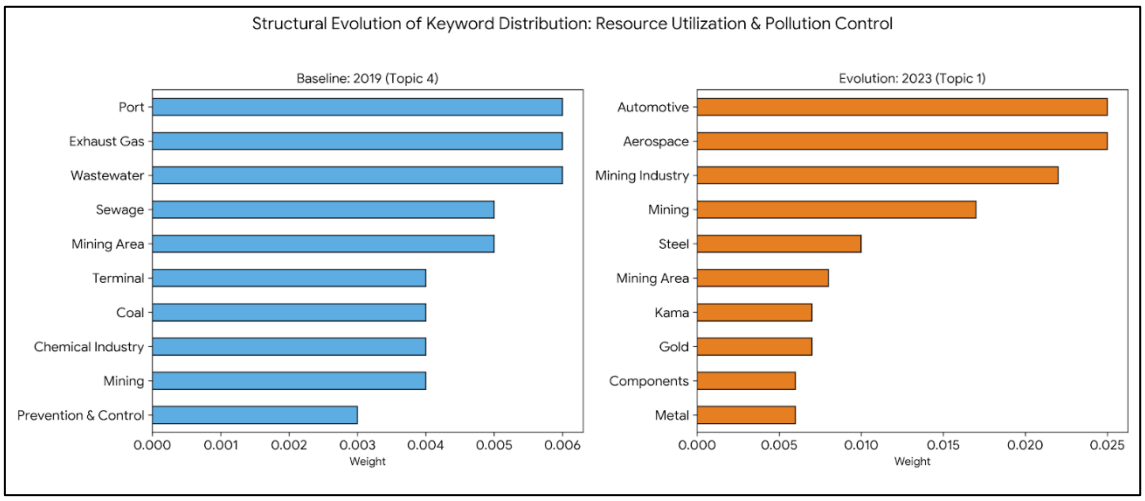

Figure 14: Structural Evolution of Keywords Distribution: Resource Utilization & Pollution Control (2019 vs. 2023)

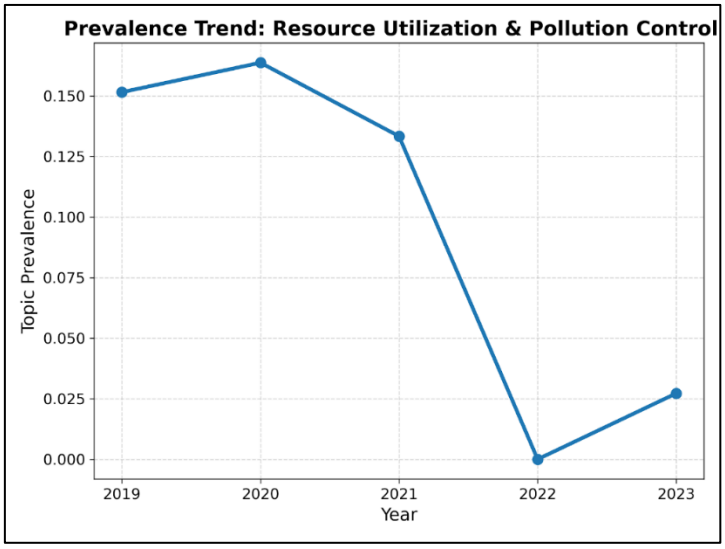

Figure 15: Prevalence Trend: Resource Utilization & Pollution Control (from 2019 to 2023)

4.2.6. Lineage 5: Medical & Bio-safety

From the perspective of topic evolution, the "Medical & Bio-safety" lineage demonstrates a high level of semantic stability throughout the sample period (see Figure 16). Across all five years, the topic was consistently taken up by sectoral-specific terms

including “medicine (医学),” “pharmaceuticals (医药),” “hospitals (医院),” “drugs (药品),” and “patients (患者),” with no substantial changes in the structural distribution. In contrast to other lineages, this theme barely exhibited obvious internal diversification or lexical replacement. The main changes in this lineage were largely confined to pandemic-related terms within the healthcare sector. The term “epidemic (疫情)” appeared with relatively high probability in 2019 and 2020, while “vaccine (疫苗)” remained a prominent term from 2019 to 2022. By 2023, although the core medical vocabulary remained stable, pandemic-specific terms no longer appeared among the high-probability keywords, indicating a convergence toward routine medical and healthcare-related disclosures.

From the perspective of annual prevalence evolution, the “Medical & Bio-safety” lineage sees a gradual declining trend over the study period (see Figure 17). Its topic prevalence decreased from 0.0501 in 2019 to 0.0368 in 2023. In spite of minor fluctuations across years, the overall decline suggests a relative reduction in the narrative weight of this theme within corporate sustainability disclosures.

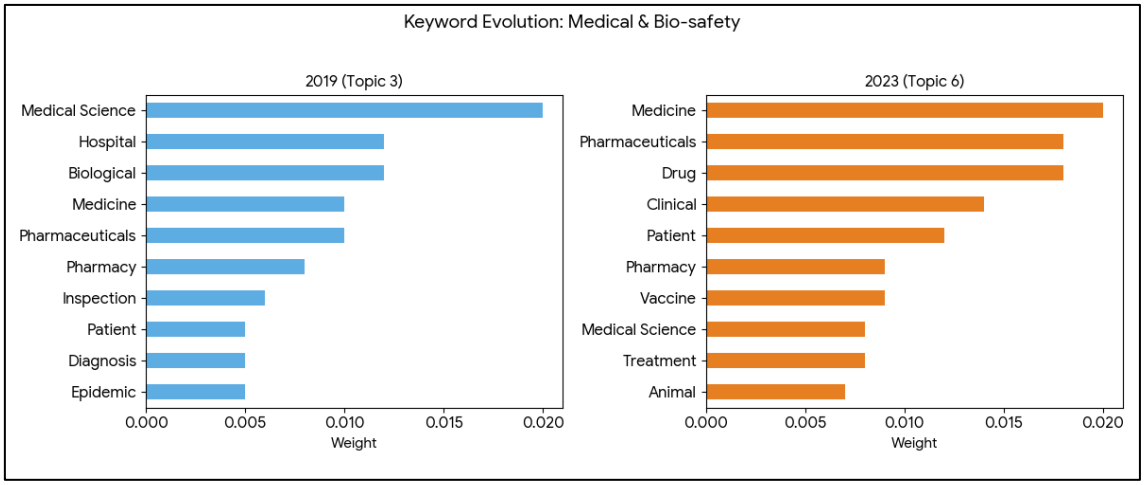

Figure 16: Structural Evolution of Keywords Distribution: Medical & Bio-safety (2019 vs. 2023)

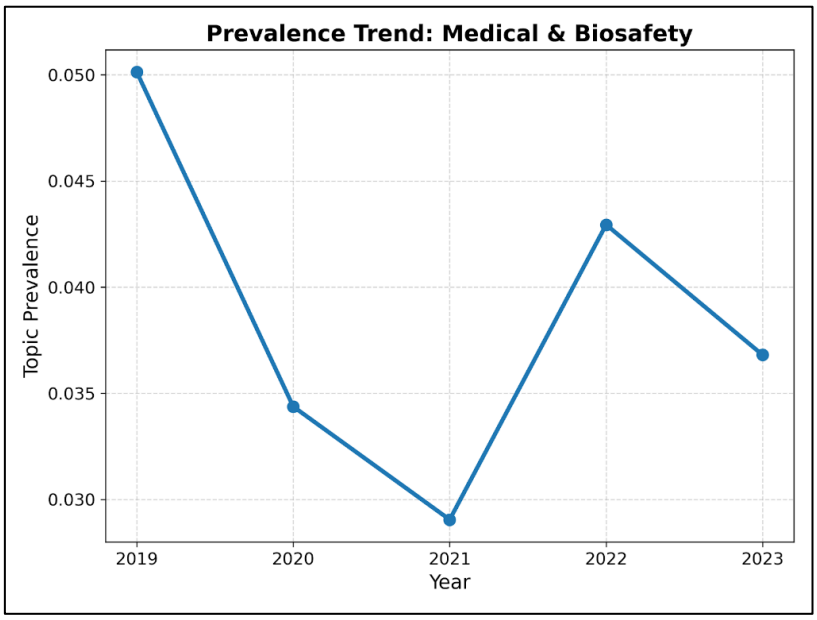

Figure 17: Prevalence Trend: Medical & Bio-safety (from 2019 to 2023)

4.3 Co-occurrence Network Structure of Corporate Sustainability Disclosure

A total of 19 keywords were selected as network nodes for the co-occurrence analysis. These keywords were chosen based on three dimensions. First, several keywords were directly related to China's "Dual Carbon" goal framework, including "Dual Carbon," "Carbon Neutrality," "Carbon Peaking," "Carbon Emissions," and "Emission Reduction," which had shown significant changes in document coverage in the previous word frequency analysis. Second, representative keywords were selected from the major thematic lineages identified in the LDA results, covering climate and emissions (e.g., "Climate Change," "Greenhouse Gases"), clean energy technologies (e.g., "New Energy," "Photovoltaics," "Wind Power," "Energy Storage"), governance and finance (e.g., "Governance," "Environmental Governance," "Green Finance," "Insurance"), and digital-related dimensions (e.g., "Digitalization," "Data Security," "Information Technology," "Cybersecurity"). Third, emerging keywords that played a connective role across different themes were secured to ensure consistency with the semantic structure outlined earlier.

By establishing co-occurrence networks for 2019 (baseline) and 2023 (post-policy), this analysis enables a comparative examination of how the relational structure among these core concepts evolved after the implementation of China's "Dual-Carbon" goal.

4.3.1. Comprehensive Structural Changes in the Co-occurrence

Network

By comparing the overall structural characteristics of the co-occurrence networks in 2019 and 2023, Figure 18 shows changes in the organization of corporate sustainability disclosure over time.

On the whole, a substantially denser and more interconnected network structure in 2023 was observed than in 2019. The network density increased remarkably from 0.3801 in 2019 to 0.5848 in 2023, which suggested a significant rise in the proportion of realized connections among all possible keyword pairs. Correspondingly, the number of valid co-occurrence relationships enlarged from 65 pairs in 2019 to 100 pairs in 2023, reflecting a clear increase in semantic linkage intensity within corporate disclosure narratives. In Figure 18, the visual contrast between the two networks reflects these structural differences directly: larger nodes indicate keywords with broader semantic connectivity, while the denser arrangement of links in 2023 reflects a higher degree of structural integration across the selected keyword set.

Besides the increase in density, the overall connectivity of the network also grew. In 2019, only 15 out of the 19 selected keywords appeared in co-occurrence pairs, while two keywords, “Carbon Peaking” and “Dual Carbon,” were completely isolated, with their degree centrality equal to 0. In other words, the keywords’ isolation meant they did not co-occur with other keywords. This structural feature aligns with the empirical context of the sample period, as these concepts had not yet been formally introduced into policy discourse at that time. In contrast, in 2023, all 19 keywords were fully integrated into the network, with no isolated nodes observed. This finding indicates a comprehensive expansion of semantic coverage in the 2023 co-occurrence network.

From a structural perspective, the 2019 co-occurrence network exhibited a relatively loose and uneven configuration because its co-occurrence relationships concentrated around a limited number of keywords and it possessed weak linkages across different semantic areas. Conversely, the 2023 network displayed a more focused and complex configuration, with a pattern of denser interconnections and a higher degree of overall cohesion. This transformation suggests that corporate sustainability disclosure evolved from a relatively fragmented structure toward a more integrated semantic system over the study period.

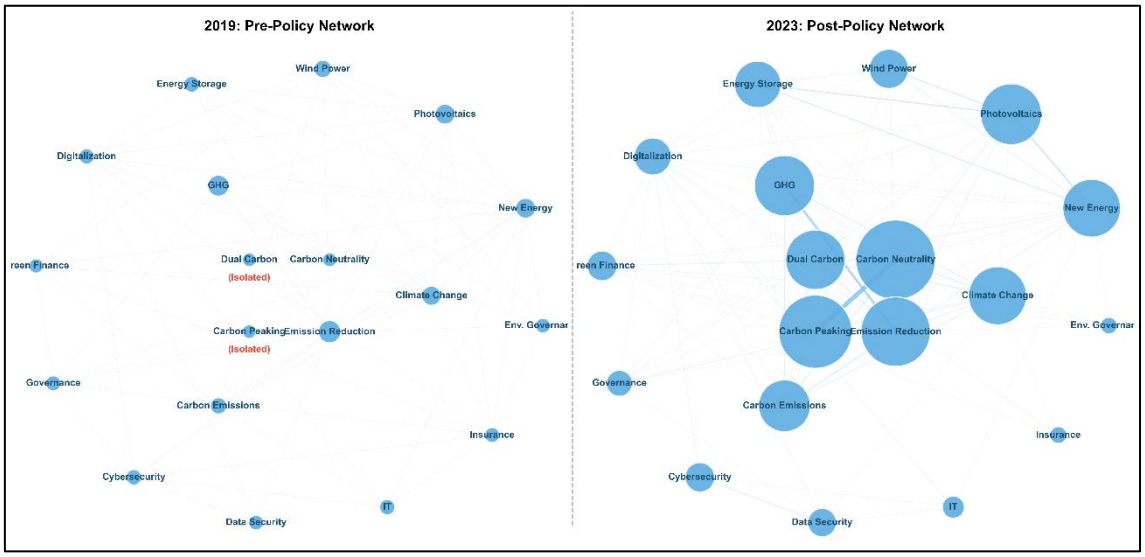

Figure 18: Co-occurrence Network (2019 vs. 2023)

4.3.2. Shifts in Core Keywords

In 2019, the co-occurrence network was characterized by a small number of core keywords. "New Energy" and "Emission Reduction" occupied the most central positions. "New Energy" showed the highest degree centrality (14) and a high normalized weighted degree (12.58), with extensive connections to technology-related keywords such as "Photovoltaics," "Wind Power," and "Energy Storage." Meanwhile, "Emission Reduction" demonstrated the strongest co-occurrence intensity in the network, with a normalized weighted degree of 19.46. It was closely linked to environmental keywords like "Greenhouse Gas," "Climate Change," and "Carbon Emissions." In contrast, policy-focused concepts such as "Carbon Neutrality" and "Dual Carbon" remained isolated during the baseline period.

In 2023, the distribution of core keywords changed significantly. "Dual Carbon" emerged as the most prominent core keyword, displaying both high degree centrality (15) and the highest normalized weighted degree (94.25) among all selected keywords. It formed strong co-occurrence pairs with multiple keywords related to climate or policy, including "Carbon Neutrality," "Carbon Peaking," "Emission Reduction," "Climate Change," and "Carbon Emissions." Meanwhile, "New Energy", with a degree centrality of 17 and a normalized weighted degree of 88.64, continued to hold a central position. Similarly, "New Energy" was still surrounded by "Photovoltaics (98.95)" and "Energy Storage (55.42), but their roles were increasingly embedded within a broader carbon-focused semantic structure rather than functioning as independent cores.

Overall, the comparison between 2019 and 2023 reveals a clear reconfiguration of core

keywords within the co-occurrence network, marked by the emergence of carbon-related policy concepts as dominant semantic anchors. This shift was identified through the combined changes in degree centrality, normalized weighted degree, and network position. In 2019, “Dual Carbon” did not form a core node in the network and remained outside the main co-occurrence structure. By 2023, it showed a degree centrality of 15 and a normalized weighted degree of 94.25, indicating that it was connected with a broader range of selected keywords and appeared with higher co-occurrence intensity. Therefore, the increased centrality of “Dual Carbon” was supported by both the quantitative indicators and its more connected position in the visualized network.

4.3.3. Emergence of Multiple Hubs in the Network

The co-occurrence network in 2023 also indicated a clear transition from a single-core structure to a multi-hub configuration. In 2019, the network was mainly organized around two major hubs, which were “New Energy” and “Emission Reduction.” However, most other keywords were positioned far from the center with relatively low degree centrality and weighted degree. The overall structure was therefore characterized by a limited number of central nodes and a weak differentiation among secondary keywords.

By contrast, the 2023 network displayed that multiple highly connected hubs were functioning simultaneously (see Figure 19). Aside from “Dual Carbon,” which held the most central position with a degree centrality of 15 and a normalized weighted degree of 94.25, several other keywords also demonstrated increased structural importance. “New Energy” remained a major hub with a degree centrality of 17 and a normalized weighted degree of 88.64 and maintained strong connections with technological keywords such as “Photovoltaics” and “Energy Storage.” At the same time, “Emission Reduction” continued to function as a key node within the carbon-related theme since it presented high connectivity with “Carbon Emissions,” “Greenhouse Gas,” and “Climate Change.”

Overall, the emergence of multiple hubs in the co-occurrence network of 2023 reflects a more complex semantic structure. In this new structure, carbon policy concepts, energy technologies, and governance-related keywords jointly contribute to the organization of corporate sustainability disclosure narratives.

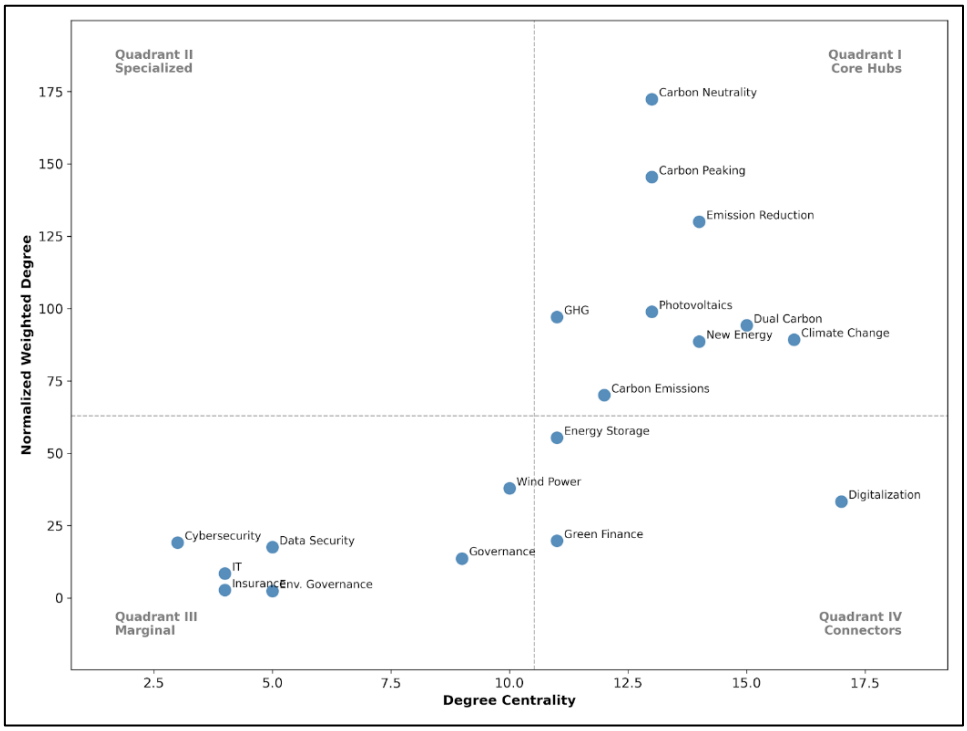

Figure 19: Strategic Matrix of Keyword Centrality and Intensity in 2023

4.3.4. Connector Keywords across Semantic Clusters

The 2023 co-occurrence network also revealed that connector keywords bridging other distinct semantic clusters were becoming more important. In 2019, cross-cluster connections were relatively limited. Most keywords were embedded within narrowly defined thematic groups, such as energy technologies or environmental ones and only a small number of nodes played an intermediary role between these groups. For example, “Digitalization” showed a moderate degree centrality and was mainly connected with keywords related to technology and finance, but its links with carbon-related keywords remained weak.

In 2023, several keywords had evolved into strong structural connectors, linking carbon policy concepts, energy technologies, and governance-related themes. Among them, “Digitalization” exhibited a notable increase in both degree centrality and normalized weighted degree and formed direct co-occurrence pairs with keywords from multiple clusters, including “Dual Carbon,” “New Energy,” “Governance,” and “Data Security.” This pattern indicates that “Digitalization” no longer functions as an external technological concept but has become embedded across different dimensions of corporate sustainability disclosure.

Similarly, “Governance” appeared as another important connector keyword in 2023.

This keyword was seen to expand its connections with “Dual Carbon,” “Climate Change,” “Carbon Emissions,” as well as with digital-related terms such as “Cybersecurity” and "Data Security." These enlarged connections suggested a growing semantic overlap between carbon strategies and governance-related discourse. To compare, “Governance” primarily co-occurred with compliance-oriented or environmental management keywords in 2019, while its role in 2023 became more integrative across multiple clusters.

From the perspective of major indicators, these connector keywords did not necessarily display the highest weighted degrees in the network as those in core hubs. However, their relatively high degree centrality across different semantic clusters highlights their structural function as bridges rather than anchors. Overall, the increased prominence of connector keywords in 2023 reflects a shift toward a more interconnected narrative structure. Under this trend, carbon policy, energy transition, digital infrastructure, and governance issues are increasingly discussed in combination rather than in isolation.

4.4 Evolution of Corporate Sustainability Disclosure Sentiment

4.4.1. Attention Toward "Dual Carbon" Goal

To further examine how Chinese listed companies have responded to the “Dual Carbon” policy agenda at the narrative level, this section focuses on the normalized keyword frequency of “Dual Carbon” related terms within sustainability disclosures. Unlike the broader keyword coverage analysis presented in Section 4.1, which captures the overall structural evolution of sustainability disclosure across multiple thematic domains, the present analysis specifically targets policy-oriented terminology associated with carbon peaking, carbon neutrality, and related climate governance concepts. By examining the normalized keyword frequency of these predefined “Dual Carbon” terms, this analysis provides a direct measure of corporate attention toward the “Dual Carbon” goal. This indicator serves as an important complement to the structural analysis, as it allows for the assessment of whether “Dual Carbon” related narratives have become more prominent within corporate sustainability disclosures over time, thereby reflecting the extent to which companies have adapted their disclosure practices in response to the evolving institutional environment.

The Dual Carbon keyword vocabulary used in this analysis consists of sixteen predefined terms that capture the core components of the “Dual Carbon” goal. These keywords include “Carbon Peaking (碳达峰)”, “Carbon Neutrality (碳中和)”, “Dual

Carbon (双碳)", "Energy Saving (节能)", "Emission Reduction (减排)", "Carbon Reduction (降碳)", "Low Carbon (低碳)", "Carbon Sink (碳汇)", "Energy Consumption (能耗)", "Carbon Emission (碳排放)", "Carbon Emission Rights (碳排放权)", "Greenhouse Gas (温室气体)", "Carbon Dioxide (二氧化碳)", "New Energy (新能源)", "Renewable Energy (可再生能源)", and "Clean Energy (清洁能源)". These terms collectively represent key policy objectives, emission-related concepts, and energy transition pathways associated with the Dual Carbon agenda. By focusing on this predefined keyword vocabulary, the analysis ensures that the measurement of normalized keyword frequency directly reflects corporate attention toward "Dual Carbon" goal narratives. The complete keyword list is presented in Table 3.

Table 3 "Dual Carbon" Keyword Vocabulary

Keyword	Frequency in "Guidance"	Coverage Rate in "Guidance"	Frequency in "Plan"	Coverage Rate in "Plan"
Carbon Peaking	31	2.40%	60	2.36%
Carbon Neutrality	31	2.40%	20	0.79%
Dual Carbon	NA	NA	NA	NA
Energy Saving	22	1.70%	46	1.81%
Emission Reduction	4	0.31%	8	0.31%
Carbon Reduction	4	0.31%	22	0.86%
Low Carbon	49	3.80%	68	2.67%
Energy Consumption	16	1.24%	13	0.51%
Carbon Emission Rights	NA	NA	NA	NA
Carbon Emission	3	0.23%	5	0.20%
Greenhouse Gas	3	0.23%	NA	NA
Carbon Dioxide	9	0.70%	7	0.28%
Carbon Sink	11	0.85%	12	0.47%
New Energy	7	0.54%	10	0.39%
Renewable Energy	7	0.54%	16	0.63%
Clean Energy	3	0.23%	5	0.20%

A clear upward trend was observed in the normalized keyword frequency of "Dual Carbon" terms between 2019 and 2023. Specifically, the overall normalized keyword frequency increased from 25.07 occurrences per 10000 words in 2019 to 52.60 occurrences per 10000 words in 2023, representing more than a twofold increase over the five-year period. While the increase between 2019 and 2020 remained relatively modest, a noticeable acceleration emerged beginning in 2021, followed by continued growth

through 2022 and 2023. This pattern suggests that "Dual Carbon" related terminology has become increasingly integrated into corporate sustainability disclosures. The consistent rise in normalized keyword frequency indicates that climate-related policy narratives have gained greater prominence within corporate reporting practices, reflecting a gradual shift in disclosure emphasis toward carbon neutrality, emission reduction, and related governance themes.

A consistent ownership-based difference was observed in the normalized keyword frequency of "Dual Carbon" terms. Throughout the entire observation period, SOEs exhibited higher normalized keyword frequency compared to non-SOEs. In 2019, the normalized keyword frequency was 28.18 occurrences per 10,000 words for SOEs, compared to 21.49 for non-SOEs (see Figure 20). This gap persisted and widened over time, reaching 58.00 for SOEs and 47.22 for non-SOEs in 2023. Both groups demonstrated a clear upward trend, particularly after 2020, but the consistently higher values observed among SOEs indicate a stronger integration of "Dual Carbon" related terminology within their sustainability disclosures. This ownership-based difference suggests that the expansion of Dual Carbon discourse occurred across all types of firms, while exhibiting varying levels of prominence depending on organizational characteristics.

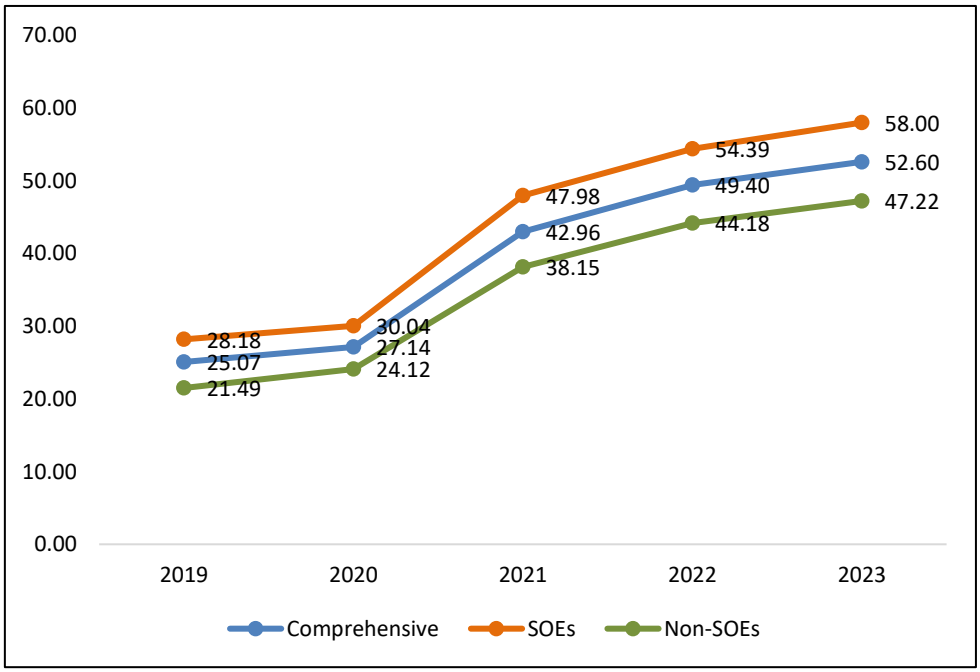

Figure 20 Normalized Keyword Frequency Comparison

4.4.2. Comprehensive Sentiment Evolution

To examine the overall tone of corporate sustainability disclosures, sentiment analysis

was conducted at the document level using the methodology described in Section 3.3.4. The comprehensive sentiment score reflects the balance between positive and negative sentiment expressed throughout the full disclosure text. Descriptive statistics of comprehensive sentiment scores by year are presented in Table 4. The mean sentiment score remained positive throughout the observation period, but showed a gradual decline from 0.7026 in 2019 to 0.6355 in 2023. A similar pattern was observed for the median sentiment score, which decreased from 0.7241 in 2019 to 0.6489 in 2023. The standard deviation increased slightly from 0.1399 in 2019 to 0.1522 in 2023, indicating a modest rise in cross-firm variation in disclosure tone. The minimum and maximum values remained stable across years (Min = 0.1877; Max = 0.9244), while the number of observations increased from 1,028 in 2019 to 2,258 in 2023. Overall, comprehensive sentiment scores stayed positive, while exhibiting a moderate downward trend over time.

In addition to overall sentiment scores, the composition of sentiment was further examined by analyzing the proportions of positive and negative words within the disclosure texts. As shown in Table 6, positive words consistently accounted for a substantially larger share of the text than negative words across all years. The positive word proportion declined slightly from 13.29% in 2019 to 12.91% in 2023, whereas the negative word proportion increased from 2.55% to 3.15% over the same period. This compositional pattern is consistent with the observed downward trend in comprehensive sentiment scores. In terms of absolute counts, both positive and negative word counts increased alongside the growth of the corpus (Total Words increased from 2,564,571 in 2019 to 9,999,479 in 2023). Overall, while positive sentiment remained dominant in corporate sustainability disclosures, the relative prominence of negative sentiment increased over time.

To further evaluate whether the observed temporal pattern reflects a statistically meaningful trend, a simple regression analysis was conducted using year as the independent variable and the comprehensive sentiment score as the dependent variable(see Table 5). The regression coefficient of year was negative and statistically significant ($\beta = -0.01556$, $p < 0.001$), indicating that the overall tone of corporate sustainability disclosure declined systematically over the observation period. The 95% confidence interval of the year coefficient remained entirely below zero, providing further support for the robustness of this downward trend. At the same time, the relatively low R^2 value suggests that year captures only a limited proportion of the total variation in sentiment scores. Therefore, the regression result should be interpreted as statistical support for a gradual downward trend in disclosure tone over time, instead of as a comprehensive explanation of sentiment variation across firms.

Table 4 Comprehensive Sentiment score descriptive statistics

Year	N	Mean	SD	Min	Median	Max
2019	1028	0.7026	0.1399	0.1877	0.7241	0.9244
2020	1147	0.6794	0.1398	0.1877	0.7042	0.9244
2021	1496	0.6767	0.1478	0.1877	0.7023	0.9244
2022	1874	0.6633	0.1495	0.1877	0.6810	0.9244
2023	2258	0.6355	0.1522	0.1877	0.6489	0.9244

Table 5 Regression Analysis of Comprehensive Sentiment Scores

Variable	Coefficient	Std. Error	t value	p value	95% CI
Intercept	32.12034	2.444544	13.1396	< 0.001	[27.32838, 36.9123]
Year	-0.01556	0.001209	-12.8674	< 0.001	[-0.01793, -0.01319]

Model statistics: $R^2 = 0.0208$; Adjusted $R^2 = 0.0207$; $F = 165.5704$; $p < 0.001$; $N = 7803$.

Table 6 Comprehensive Sentiment Composition

Year	Pos. Words	Neg. Words	Total Words	Pos. proportion	Neg. Proportion
2019	340799	65456	2564571	13.29%	2.55%
2020	400778	83078	3113613	12.87%	2.67%
2021	606598	126825	4646157	13.06%	2.73%
2022	880666	193879	6764357	13.02%	2.87%
2023	1290494	314767	9999479	12.91%	3.15%

4.4.3. "Dual Carbon" Semantic Window Sentiment Evolution

To examine sentiment specifically associated with “Dual Carbon” disclosure narratives, sentiment analysis was conducted using the semantic window extraction method described in Section 3.3.4. This approach isolates sentiment expressed in the immediate contextual vicinity of Dual Carbon keywords, thereby providing a policy-specific measure of disclosure tone. Descriptive statistics of semantic window sentiment scores are presented in Table 7. The mean sentiment score remained positive throughout the observation period, with values of 0.5378 in 2019, 0.5295 in 2020, 0.5358 in 2021, 0.5299 in 2022, and 0.5094 in 2023. A similar pattern was observed in the median sentiment score, which declined from 0.5448 in 2019 to 0.5096 in 2023. The standard deviation decreased from 0.1813 in 2019 to 0.1369 in 2023, indicating reduced variation in Dual Carbon–related disclosure tone across firms over time. The number of valid observations increased from 910 in 2019 to 2,184 in 2023, consistent with the overall expansion of the

disclosure corpus and the increasing availability of Dual Carbon–related text segments for window-based analysis. Compared to comprehensive sentiment scores, semantic window sentiment scores were consistently lower across all years, indicating a more moderate tone within Dual Carbon–specific disclosure contexts.

To further evaluate whether the observed temporal pattern reflects a statistically meaningful trend, a simple regression analysis was conducted using year as the independent variable and the "Dual Carbon" semantic window sentiment score as the dependent variable (see Table 8). The regression coefficient of year was negative and statistically significant ($\beta = -0.00655$, $p < 0.001$), indicating that the tone of policy-specific disclosure also declined systematically over the observation period. The 95% confidence interval of the year coefficient remained entirely below zero, providing further support for the robustness of this downward trend. At the same time, the relatively low R^2 value suggests that year explains only a limited proportion of the total variation in semantic window sentiment scores. Therefore, this regression result should be interpreted as statistical support for a gradual moderation in "Dual Carbon" related disclosure tone over time, instead of as a comprehensive explanation of sentiment variation across firms.

Apart from sentiment scores, the composition of sentiment within "Dual Carbon" semantic windows was further examined by analyzing the proportions of positive and negative words. As shown in Table 9, positive words consistently accounted for a substantially larger share of the text than negative words throughout the observation period. The positive word proportion declined gradually from 21.45% in 2019 to 19.72% in 2023, while the negative word proportion remained relatively stable, fluctuating between 1.66% and 2.16% across years. This pattern is also reflected in the absolute counts of sentiment words, where the number of positive words increased from 30,845 in 2019 to 214,230 in 2023, and the number of negative words increased from 3,018 to 18,412 over the same period. Despite the increase in absolute counts due to the expansion of the disclosure corpus, the relative proportions indicate a gradual moderation in sentiment intensity within "Dual Carbon" related disclosure contexts. Overall, positive sentiment remained dominant in "Dual Carbon" narratives, while exhibiting a slight decline in relative prominence over time.

Table 7 "Dual Carbon" Semantic Window Sentiment score descriptive statistics

Year	N	Mean	SD	Min	Median	Max
2019	910	0.5378	0.1813	0.0708	0.5448	0.8661
2020	1037	0.5295	0.1808	0.0708	0.5362	0.8661
2021	1407	0.5358	0.1628	0.0708	0.5417	0.8661
2022	1803	0.5299	0.1473	0.0708	0.5297	0.8661
2023	2184	0.5094	0.1369	0.0708	0.5096	0.8661

Table 8 Regression Analysis of "Dual Carbon" Semantic Window Sentiment Scores

Variable	Coefficient	Std. Error	t value	p value	95% CI
Intercept	13.77319	2.713242	5.076286	< 0.001	[8.45446, 19.09193]
Year	-0.00655	0.001342	-4.88247	< 0.001	[-0.00918, -0.00392]

Model statistics: $R^2 = 0.0032$; Adjusted $R^2 = 0.0031$; $F = 23.8385$, $p < 0.001$; $N = 7341$.

Table 9 "Dual Carbon" Semantic Window Sentiment Composition

Year	Pos. Words	Neg. Words	Total Words	Pos. proportion	Neg. Proportion
2019	30845	3018	143801	21.45%	2.10%
2020	39287	4006	185283	21.20%	2.16%
2021	85417	7141	408191	20.93%	1.75%
2022	140428	11454	690515	20.34%	1.66%
2023	214230	18412	1086283	19.72%	1.69%

4.4.4. Ownership-Based Sentiment Differences

To examine heterogeneity in "Dual Carbon" related disclosure tone across ownership structures, semantic window sentiment scores were compared between SOEs and non-SOEs. Descriptive statistics are presented in Table 10 and Table 11. For SOEs, the mean sentiment score exhibited moderate variation over time, with values of 0.5287 in 2019 and 0.5240 in 2020, followed by an increase to 0.5431 in 2021 and 0.5438 in 2022, and a subsequent decline to 0.5259 in 2023. A similar temporal pattern was observed in the median sentiment score, which increased between 2020 and 2021 before declining in later years. In addition, the standard deviation decreased steadily from 0.1805 in 2019 to 0.1249 in 2023, indicating reduced cross-firm variation in sentiment among SOEs over time. In contrast, non-SOEs exhibited a more consistent downward trend, with mean sentiment scores declining progressively from 0.5480 in 2019 to 0.5352 in 2020, 0.5261 in 2021, 0.5142 in 2022, and 0.4943 in 2023. A similar declining pattern was observed in

the median sentiment score for non-SOEs, indicating a consistent downward shift in disclosure tone. The standard deviation also decreased over time. Specifically, the standard deviation of non-SOEs decreased from 0.1838 in 2019 to 0.1457 in 2023, suggesting reduced variation in sentiment among non-SOEs. While non-SOEs initially exhibited higher sentiment scores than SOEs, this difference narrowed over time, and SOEs exhibited slightly higher sentiment scores in the later years of the observation period. Overall, both ownership groups maintained positive sentiment scores throughout the study period, while exhibiting distinct temporal patterns in sentiment evolution.

Table 10 SOEs Sentiment score descriptive statistics

Year	N	Mean	SD	Min	Median	Max
2019	489	0.5287	0.1805	0.0686	0.5381	0.8571
2020	521	0.5240	0.1783	0.0686	0.5345	0.8571
2021	663	0.5431	0.1561	0.0686	0.5527	0.8571
2022	889	0.5438	0.1378	0.0686	0.5417	0.8571
2023	1031	0.5259	0.1249	0.0686	0.5279	0.8571

Table 11 Non-SOEs Sentiment score descriptive statistics

Year	N	Mean	SD	Min	Median	Max
2019	394	0.5480	0.1838	0.0712	0.5569	0.8667
2020	487	0.5352	0.1834	0.0712	0.5417	0.8667
2021	712	0.5261	0.1683	0.0712	0.5278	0.8667
2022	887	0.5142	0.155	0.0712	0.5109	0.8667
2023	1110	0.4943	0.1457	0.0712	0.4905	0.8667

Besides, differences in sentiment composition between SOEs and non-SOEs were examined by comparing the proportions of positive and negative words within “Dual Carbon” semantic windows. As shown in Table 12 and Table 13, positive words accounted for a substantially larger share of disclosure text than negative words for both ownership groups throughout the observation period. For SOEs, the positive word proportion remained relatively stable, decreasing slightly from 21.37% in 2019 to 20.52% in 2023, while the negative word proportion declined from 2.04% to 1.60% over the same period. In contrast, non-SOEs exhibited a more pronounced decline in positive word proportion, decreasing from 21.63% in 2019 to 18.80% in 2023. The negative word proportion for non-SOEs also decreased modestly, from 2.20% to 1.81%. Despite the increase in the absolute number of sentiment words due to the expansion of disclosure content, positive sentiment remained dominant across both ownership groups. Overall,

these results indicate that both SOEs and non-SOEs maintained predominantly positive sentiment in Dual Carbon–related disclosure, while non-SOEs exhibited a more noticeable reduction in positive sentiment proportion over time.

Table 12 SOEs Sentiment Composition

Year	Pos. Words	Neg. Words	Total Words	Pos. proportion	Neg. Proportion
2019	18682	1784	87408	21.37%	2.04%
2020	22233	2205	104808	21.21%	2.10%
2021	46457	3667	216616	21.45%	1.69%
2022	80065	6023	382221	20.95%	1.58%
2023	117695	9191	573482	20.52%	1.60%

Table 13 Non-SOEs Sentiment Composition

Year	Pos. Words	Neg. Words	Total Words	Pos. proportion	Neg. Proportion
2019	11579	1175	53524	21.63%	2.20%
2020	16128	1713	76344	21.13%	2.24%
2021	37077	3374	183413	20.22%	1.84%
2022	58602	5343	300352	19.51%	1.78%
2023	93296	8964	496315	18.80%	1.81%

Welch's t-tests were conducted to further examine whether the observed ownership differences in sentiment scores were statistically significant, with comparing mean semantic window sentiment scores between SOEs and non-SOEs for each year. The results are presented in Table 14. In 2019 and 2020, the differences in mean sentiment scores between SOEs and non-SOEs were not statistically significant ($t = -1.564$, $p = 0.118$; $t = -0.982$, $p = 0.326$, respectively). In 2021, the difference became more pronounced, although it remained marginally significant ($t = 1.943$, $p = 0.052$). In contrast, statistically significant differences emerged in 2022 and 2023. Specifically, SOEs exhibited significantly higher sentiment scores than non-SOEs in 2022 ($t = 4.253$, $p < 0.001$) and 2023 ($t = 5.399$, $p < 0.001$). These results provide statistical evidence that ownership-based differences in "Dual Carbon" related disclosure tone became more pronounced in the later years of the observation period.

To complement the p-value-based comparison, a standardized mean difference, reported as Cohen's d, was calculated to assess the magnitude of the mean differences between SOEs and non-SOEs. This effect size was used as a descriptive indicator alongside the Welch t-test results. The results show that the effect sizes were small across all years. In 2019 and 2020, the differences were negative but small, indicating slightly

higher semantic window sentiment scores among non-SOEs. From 2021 onward, the direction of the difference shifted, and SOEs showed higher mean scores than non-SOEs. The effect size increased from 0.105 in 2021 to 0.202 in 2022 and 0.232 in 2023, suggesting a small but gradually clearer ownership-based divergence in disclosure tone. Therefore, the statistically significant differences in 2022 and 2023 should be interpreted as modest differences in magnitude, while still supporting the finding that non-SOEs exhibited a more pronounced moderation in "Dual Carbon" related disclosure tone.

Table 14 T-test for Mean Differences between SOEs and Non-SOEs

Year	Mean Diff (SOE−Non)	Welch t-value	df	*p*-value	Cohen's d	Significance
2019	−0.0193	−1.564	835.02	0.1183	-0.106	not significant
2020	−0.0112	−0.982	996.87	0.3263	-0.062	not significant
2021	0.0170	1.943	1372.98	0.0522	0.105	marginal
2022	0.0296	4.253	1749.1	$p < 0.001$	0.202	significant
2023	0.0316	5.399	2125.5	$p < 0.001$	0.232	significant

4.5 Summary

This chapter presented the empirical findings on the structural and sentiment evolution of corporate sustainability disclosure among Chinese-listed companies from 2019 to 2023. The results revealed systematic changes in thematic attention, semantic structure, and disclosure tone during this period.

Keyword coverage analysis showed a clear increase in attention toward carbon-related concepts, indicating that "Dual Carbon" related topics became more prominent within corporate sustainability disclosure. Topic modeling results further demonstrated a shift in thematic organization, with climate-related themes emerging as dominant components of disclosure narratives, while traditional pollution-control themes declined in prominence. Co-occurrence network analysis provided additional evidence of structural evolution, showing that "Dual Carbon," "Carbon Neutrality," and "Carbon Peaking" emerged as central semantic hubs, while concepts such as "Digitalization" and "Governance" functioned as structural connectors facilitating integration across thematic domains.

Sentiment analysis results revealed a gradual moderation in disclosure tone across the study period. Although sustainability disclosure remained generally positive, both comprehensive sentiment scores and policy-specific sentiment scores exhibited a declining trend. Ownership-based analysis further showed that non-SOEs experienced more pronounced tonal moderation compared to SOEs, indicating variation in disclosure tone across ownership types.

Overall, the results presented in this chapter demonstrate that corporate sustainability disclosure underwent coordinated structural and tonal evolution during the study period. The central empirical finding can be summarized as structural expansion accompanied by sentiment moderation. Structural expansion was reflected in the increased prominence of carbon-related keywords, the emergence of climate-oriented thematic lineages, and the movement of “Dual Carbon” related concepts toward the center of the co-occurrence network. Sentiment moderation was reflected in the gradual decline of both comprehensive sentiment scores and “Dual Carbon” semantic window sentiment scores, with a more visible moderation among non-SOEs. These findings provide the empirical basis for interpreting how disclosure practices evolved under the “Dual Carbon” goal, which is examined in greater depth in Chapter 5.

Chapter 5
Discussion

This chapter provides an interpretive analysis of the empirical findings presented in Chapter 4. While the previous chapter documented structural and sentiment evolution in corporate sustainability disclosure among Chinese-listed companies, the present chapter examines how these patterns may be understood within broader theoretical contexts. Specifically, the observed expansion of carbon-related disclosure and moderation of disclosure tone are interpreted through the perspectives of institutional theory and signaling theory. These theoretical lenses offer complementary insights into how organizations adjust disclosure practices under changing policy environments and stakeholder expectations.

The chapter is organized into three main sections. Section 5.1 interprets the findings within the institutional context, focusing on how sustainability disclosure reflects processes of institutional alignment. Section 5.2 examines disclosure evolution from a signaling perspective, highlighting how disclosure structure and tone may function as communicative signals. Section 5.3 integrates structural and sentiment findings to provide a comprehensive interpretation of disclosure evolution. Through this interpretive framework, the chapter develops a theoretical understanding of how corporate sustainability disclosure evolved under the “Dual Carbon” goal.

5.1 Institutional Interpretation

5.1.1. Disclosure Reorganization under Institutional Change

The results of this study suggest that China’s "Dual-Carbon" goal constituted a major institutional intervention associated with substantial changes in the structure and focus of corporate sustainability disclosure. Through word frequency analysis, LDA topic modeling, and co-occurrence network results, a distinct pattern emerges, which is climate-related concepts shifted from peripheral mentions to central organizing elements of corporate sustainability disclosure, after 2020.

From an institutional perspective, this transformation can be interpreted as a response to strengthened regulatory and normative pressure. Institutional theory argues that firms tend to adjust their organizational practices and disclosure strategies in response to dominant rules, expectations, and policy signals in their external environment (DiMaggio

& Powell, 2000). The rapid rise in document coverage of policy-specific terms such as “Dual Carbon,” “Carbon Neutrality,” and “Carbon Peaking” after 2020 provides clear empirical evidence that corporate narratives became closely aligned with the national strategic agenda. Instead of keeping the same pace on general environmental commitment, Chines-listed companies increasingly adopted the official policy vocabulary, indicating a convergence toward institutionally legitimized discourse.

However, the process of institutional realignment contained substantial heterogeneity across organizational types, particularly with respect to ownership. The ownership-based analysis indicated that SOEs and non-SOEs performed differently in the intensity and manner of their discursive alignment with the “Dual Carbon” goal. While both groups exhibited rising attention to keywords directly related to the “Dual Carbon” goal after 2020, SOEs consistently demonstrated stronger incorporation of policy-framed keywords, particularly those explicitly linked to national strategy. Applying the institutional theory to interpret this divergence, differences in organizational embeddedness can be observed within the state policy system. As units or organizations more affiliated with governmental authority and political accountability structures, SOEs face stronger normative pressure(W. Li & Zhang, 2010; Marquis & Qian, 2014). Therefore, they indicated a preference for signaling alignment with national strategic goals in sustainability reporting. Conversely, non-SOEs appear to pay more balanced attention among generalized environmental and sustainability narratives, and the “Dual Carbon” goal. This tendency suggests that non-SOEs face alternative pathways of legitimacy construction oriented toward market and societal audiences (W. Li & Zhang, 2010; Marquis & Qian, 2014).

To be clear, this institutional realignment was not just about keyword frequency or document coverage. The LDA results demonstrate that "Climate & Emission Strategy" became the most prominent thematic line, and the co-occurrence network analysis shows that carbon-related concepts became key semantic anchors linking multiple clusters. This indicates that Chinese-listed companies did not merely add new climate-related terms to their existing sustainable disclosures but reorganized their reporting structure around carbon governance as a central strategic focus. Similar shifts have been seen in previous studies examining how major environmental policies influence corporate reporting priorities by redefining what is considered legitimate and relevant disclosure (Marquis & Qian, 2014).

At the same time, the lasting presence of broad sustainable concepts such as “Environmental Protection” and “Green Development” indicates that institutional change occurred through specification rather than replacement. Instead of eliminating earlier

environmental narratives, Chinese-listed companies embedded carbon-focused disclosure within an expanded sustainability framework. This pattern is consistent with institutional gradualism, where new rules and expectations are integrated into existing practices over time rather than replacing them entirely(Mahoney & Thelen, 2009).

As a whole, the findings suggest that the "Dual-Carbon" goal functioned as a powerful institutional signal that redefined the cognitive and normative boundaries of corporate sustainability disclosure. Chinese-listed companies responded by restructuring their narratives to emphasize carbon-related strategies, measurement, and governance, to align disclosure practices with evolving institutional expectations.

5.1.2. From Pollution Control to Climate Strategy

The results suggest a clear shift in the narrative logic of corporate sustainability disclosure from traditional pollution control to a more strategic climate-focused framework. From an institutional perspective, this shift may reflect a redefinition of what constitutes legitimate environmental responsibility under the "Dual-Carbon" goal framework.

Chinese-listed companies face increasing pressure to demonstrate alignment with the "Dual-Carbon" goal, which helps explain the rapid rise of carbon-related and policy-linked terms after 2020. This trend is especially visible in the strong growth of policy-linked terms such as "Dual Carbon," "Carbon Neutrality," and "Carbon Peaking", as well as the significant increase in carbon-related terms such as "Carbon Emissions," "Emission Volume," and "Emission Reduction."

This shift is also clearly observed in the LDA topic modeling results. While the thematic lineage Climate & Emission Strategy rose sharply and became the most prominent topic in 2023, Resource Utilization & Pollution Control declined continuously and even lost semantic coherence in 2022. This trend implies a reclassification that pollution-related issues were absorbed into carbon-oriented narratives. Similar transitions have been observed in contexts where climate policy reframes environmental responsibility from operational control to strategic orientation (Delmas et al., 2008).

The co-occurrence network analysis supports this interpretation in a further respect. By 2023, carbon-related concepts, "Dual Carbon" in particular, became central semantic anchors and then reorganized corporate sustainability disclosure narratives on climate strategy.

Consequently, the findings suggest that pollution control appears to have lost its central position as the primary organizing logic of environmental disclosure, giving way to climate strategy logic shaped by institutional pressure and national policy

signals(DiMaggio & Powell, 2000).

5.1.3. Digitalization and Governance as Structural Connectors

The results indicate that digitalization and governance appeared to play important structural parts in how Chinese-listed companies articulated and organized their response to the "Dual-Carbon" goal. From an institutional perspective, policy pressure alone does not automatically translate into an effective organizational response. More importantly, firms must rely on specific tools and structures to make compliance observable, credible, and manageable (W. Scott, 2013).

The rising prominence of terms related to digitalization provides evidence for this interpretation. In the keyword frequency and co-occurrence analyses, terms such as "Digitalization," "Data Security," "Cybersecurity," and "Information Technology" became increasingly connected with carbon-related concepts after 2020. This pattern suggests that Chinese-listed companies increasingly applied digital technologies as infrastructural supports for carbon measurement, monitoring, and reporting, not as generic efficiency tools. Prior research has emphasized that digital systems play a critical role in translating abstract sustainability goals into measurable and auditable practices, thereby enhancing organizational legitimacy under regulatory scrutiny (Kellogg et al., 2020).

Meanwhile, terms related to governance gained structural importance across both the LDA and co-occurrence network results. The enhanced semantic links between "Governance" and carbon-related terms indicate that climate issues were increasingly incorporated into formal governance frameworks, not remaining limited to operational or environmental management parts. Institutional theory suggests that embedding new policy demands into governance structures is a central pathway through which organizations stabilize responses to external pressure and signal long-term commitment(DiMaggio & Powell, 2000). In this sense, governance acted as a coordinating mechanism that aligned the "Dual Carbon" goal with internal decision-making and accountability systems.

Furthermore, the joint rise of digitalization and governance highlights a complementary relationship. Digital tools provided technical support to generate carbon-related information, while governance structures defined how such information was interpreted, disclosed, and acted upon. Together, these findings suggest that digitalization and governance did not merely accompany the "Dual-Carbon" transition, but were firmly integrated into the sustainability reporting strategies of Chinese-listed companies to respond to institutional pressure in a structured and credible manner.

5.1.4. Sentiment Moderation within Institutional Context

In addition to structural reorganization, the sentiment analysis results reveal a clear pattern of tone moderation in corporate sustainability disclosure under the "Dual Carbon" goal framework. While the overall volume and structural prominence of carbon-related disclosure increased substantially after 2020, sentiment scores exhibited a gradual decline over time. Specifically, both comprehensive sentiment scores and "Dual Carbon" semantic window sentiment scores remained positive throughout the observation period but showed a consistent downward trend in their mean and median values. This indicates that although Chinese-listed companies increasingly incorporated "Dual Carbon" related concepts into their disclosure narratives, the tone of such disclosures became more measured and restrained over time.

From an institutional perspective, this pattern can be interpreted as a response to increased regulatory scrutiny and normative uncertainty associated with the implementation of the "Dual Carbon" goal. Institutional theory suggests that organizations seek to maintain legitimacy by aligning their symbolic practices with dominant policy expectations, particularly when new institutional demands emerge(DiMaggio & Powell, 2000). In the early stage of institutional transition, organizations may express stronger or more generalized positive narratives as part of initial alignment. However, as institutional expectations become more clearly defined and operationalized, organizations tend to adopt more precise and cautious disclosure practices to ensure consistency between symbolic communication and observable actions. In this context, sentiment moderation reflects an adjustment toward more disciplined and policy-aligned disclosure, rather than a reduction in engagement with sustainability issues.

Further evidence supporting this interpretation can be found in the semantic window sentiment analysis. Compared with comprehensive sentiment scores, semantic window sentiment scores were consistently lower, suggesting that disclosures specifically related to the "Dual-Carbon" goal were communicated in a more restrained tone than sustainability disclosure narratives as a whole. This difference indicates that Chinese-listed companies did not merely expand carbon-related disclosure symbolically, but also adjusted the tone of policy-specific disclosure in response to institutional expectations. Such moderation may reflect increased awareness of the credibility and accountability requirements associated with "Dual-Carbon" commitments, particularly in a policy environment where disclosure content is more closely monitored and evaluated.

Ownership-based heterogeneity in sentiment evolution provides additional insight into

the institutional dynamics underlying tone adaptation. The results show that SOEs maintained relatively stable sentiment scores over time, while non-SOEs exhibited a more pronounced decline in sentiment scores. In this study, the difference between SOEs and non-SOEs did not appear as a stable pattern from the start, but became more visible in the later stage of the observation period. This temporal pattern suggests that the divergence may be associated with the evolving policy environment of the "Dual Carbon" transition. This divergence is consistent with differences in institutional embeddedness. As organizations more directly affiliated with state authority and policy implementation structures, SOEs may experience stronger incentives to maintain stable and policy-consistent disclosure narratives. In contrast, non-SOEs may face greater uncertainty regarding regulatory expectations and operational implications, leading to more cautious tone adjustments in response to evolving institutional conditions.

Taken together, these findings indicate that sentiment moderation emerged alongside the structural reorganization of sustainability disclosure within the institutional context of the "Dual Carbon" goal. While Chinese-listed companies substantially expanded carbon-related disclosure and increased the structural prominence of climate-related concepts, the tone of such disclosure became more measured over time. This pattern suggests that structural expansion and tone moderation co-occurred as part of the broader evolution of corporate sustainability disclosure during the institutional transition period. In this sense, corporate disclosure narratives appear to have undergone both structural and tonal adjustments within the changing institutional environment. This pattern may reflect a broader process of institutional adaptation, in which organizations adjust both the content and tone of symbolic practices to maintain legitimacy within a changing policy environment.

5.1.5. Theoretical Implications for Institutional Theory

This study provides three main theoretical implications for research on institutional change and corporate sustainability disclosure.

First, our findings contribute to institutional theory by illustrating how corporate sustainability reporting reflects the institutional change under certain policies, which is through gradual realignment of disclosure narratives instead of abrupt transformation. Specifically, companies appear to incrementally enhance or weaken the relative prominence, connectivity and semantic positioning of sustainability-related topics that are significant within the ongoing policy and institutional context. This pattern aligns with views of institutional change as an evolutionary and interpretive process, in which organizations adjust symbolic practices to maintain legitimacy under shifting normative

expectations.

Second, the study advances sustainability disclosure literature by highlighting the importance of both narrative structure and narrative tone as dimensions of institutional adaptation, beyond keyword frequency or disclosure volume. By examining changes in thematic integration and semantic centrality, our analysis demonstrates that disclosure evolution can occur at the level of narrative logic and relational structure, even in the absence of direct evidence of substantive operational change. At the same time, sentiment analysis results indicate that both comprehensive and Dual Carbon–specific sentiment scores remained positive but exhibited a gradual decline over time, reflecting a shift toward more measured and restrained disclosure tone. The observed coexistence of expanding carbon-related disclosure and increasingly moderated sentiment scores suggests that institutional adaptation involves coordinated adjustments across multiple symbolic dimensions. This perspective advances institutional theory by emphasizing that organizational alignment with institutional expectations may manifest through changes in how sustainability issues are structurally integrated and symbolically communicated, instead of solely through increases in disclosure quantity.

Third, our study broadens the use of institutional theory in China's unique setting by highlighting differences in how companies symbolically align their disclosure narratives with policy signals across various organizational ownership structures. Instead of assuming all organizations respond the same way to coercive pressure, the observed differences between SOEs and non-SOEs suggest that a firm's level of institutional embeddedness influences the strength and nature of its narrative alignment. In state-led institutional environments, SOEs are more deeply embedded within the political and administrative systems and tend to show more obvious policy-focused disclosure narratives. Meanwhile, non-SOEs adopt more selective and market-driven approaches. Importantly, this distinction should be viewed as an interpretive pattern in symbolic disclosures rather than as proof of causal mechanisms. It emphasizes that corporate sustainability disclosure develops in response to external institutional signals and also depends on a firm's position within the political and economic hierarchy.

5.2 Signaling Interpretation

5.2.1. Expansion of "Dual Carbon" Disclosure as Strategic Signaling

From a signaling theory perspective, the expansion of "Dual Carbon" related disclosure

observed in this study can be interpreted as a strategic communication response to information asymmetry between firms and external stakeholders. Signaling theory suggests that organizations voluntarily disclose observable information to convey unobservable attributes, such as strategic commitment, capability, or alignment with emerging policy expectations(Connelly et al., 2011; Marquis et al., 2016; Spence, 1973). In the context of China's "Dual Carbon" goal, corporate sustainability disclosure serves as an important channel through which firms communicate their positioning within the national low-carbon transition. The observed increase in normalized keyword frequency of "Dual Carbon" keywords indicates that Chinese-listed companies increasingly incorporated policy-specific vocabulary into their disclosure narratives, thereby making their alignment with national climate objectives more visible and interpretable to regulators, investors, and other stakeholders.

The LDA topic modeling results provide further support for this interpretation. The thematic lineage Climate & Emission Strategy exhibited substantial growth and became the most prominent topic in later years of the observation period. This shift suggests that climate-related disclosure evolved into a central component of corporate sustainability communication. From a signaling perspective, the prominence of climate strategy topics enhances the observability of corporate positioning in relation to the "Dual Carbon" goal(Clarkson et al., 2008; Dhaliwal et al., 2011). By integrating policy-relevant concepts into dominant thematic structures, firms provide clearer signals regarding their awareness of policy priorities and their participation in the low-carbon transition. This form of thematic emphasis increases the informational clarity of sustainability disclosure and facilitates stakeholder interpretation of corporate strategic orientation under evolving policy conditions.

Evidence from the co-occurrence network analysis reinforces this signaling interpretation. The structural centrality of "Dual Carbon" and related carbon governance concepts increased substantially over time, and these concepts became key semantic connectors linking multiple thematic clusters. In signaling terms, concepts occupying structurally central positions carry greater communicative weight, as they shape the overall interpretation of the disclosure narrative. The emergence of "Dual Carbon" related terms as semantic hubs indicates that these concepts became integral reference points within corporate sustainability communication. This structural integration enhances the salience and consistency of policy-related signals, allowing stakeholders to more readily identify corporate alignment with national climate priorities.

Taken together, the keyword frequency, topic modeling, and network structure results suggest that the expansion of "Dual Carbon" disclosure reflects an increase in signal

visibility within corporate sustainability communication. As policy expectations became more clearly defined, Chinese-listed companies expanded the use of policy-aligned vocabulary and integrated carbon-related concepts into central narrative structures. These disclosure patterns are consistent with signaling theory, which predicts that organizations adjust observable communication practices to reduce information asymmetry and improve stakeholder understanding of organizational positioning in changing institutional environments.

5.2.2. Sentiment Moderation as Credibility Enhancing Signal

In addition to the structural expansion of "Dual Carbon" disclosure, the sentiment analysis results reveal a parallel pattern of tone moderation, which can be interpreted through the lens of signaling theory as an adjustment in signal credibility. Signaling theory suggests that the effectiveness of a signal depends on its perceived reliability and consistency with observable organizational conditions(Connelly et al., 2011; Marquis et al., 2016; Verrecchia, 1983). While highly positive disclosure may indicate strong commitment, excessively optimistic narratives may also reduce signal credibility if stakeholders perceive a gap between symbolic communication and verifiable actions. The sentiment analysis results show that both comprehensive sentiment scores and "Dual Carbon" semantic window sentiment scores remained positive throughout the observation period but exhibited a gradual decline in their mean and median values. This pattern indicates that Chinese-listed companies continued to communicate favorable sustainability positions, while simultaneously adopting a more measured tone over time. Such tone moderation may enhance the interpretability and credibility of disclosure signals, particularly in a policy environment where sustainability claims are subject to increasing scrutiny.

This interpretation is consistent with the structural evolution observed in the keyword frequency, LDA, and co-occurrence network analyses. As carbon-related terms became more prominent and structurally integrated into corporate sustainability disclosure, the communicative function of these narratives appears to have shifted toward greater informational precision. The increased centrality of "Dual Carbon" concepts within thematic and network structures suggests that policy-related disclosure became a core component of corporate communication. In this context, tone moderation may reflect an effort to align narrative tone with the increased informational importance of carbon-related disclosure. When disclosure content becomes more central to stakeholder evaluation, organizations may adopt more disciplined and balanced communication styles to maintain signal credibility (Healy & Palepu, 2001). The coexistence of expanding

disclosure volume and moderated sentiment tone suggests that Chinese-listed companies adjusted both the visibility and credibility of their sustainability signals. These patterns are consistent with signaling theory, which predicts that organizations refine observable communication characteristics to enhance signal effectiveness and reduce uncertainty in stakeholder interpretation under evolving policy conditions.

This finding further extends the signaling interpretation of sustainability disclosure within a changing policy context. Before the empirical analysis, an intuitive expectation might be that companies would adopt a more positive tone after the introduction of the "Dual Carbon" goal in order to emphasize policy alignment. However, the results show a different pattern: as "Dual Carbon" related concepts became more structurally visible, the corresponding disclosure tone became more moderate. This suggests that credibility-oriented signaling does not necessarily require more optimistic language. Under a policy-sensitive environment, a moderated tone may reduce the risk of overstatement and make disclosure signals appear more careful and accountable. Therefore, sentiment moderation can be understood as an important signaling adjustment, through which firms balance visibility and credibility in sustainability communication.

5.2.3. Ownership Differences and Signaling Strategies

Ownership-based differences in sentiment evolution provide important insight into how signaling strategies varied across organizational types during the "Dual Carbon" goal period. The sentiment analysis results indicate a clear divergence in tone trajectories between SOEs and non-SOEs. In the early stage of the observation period, non-SOEs exhibited slightly higher sentiment scores than SOEs, although the difference was not statistically significant. Over time, however, this pattern gradually reversed. By the later stage of the observation period, non-SOEs exhibited noticeably lower sentiment scores than SOEs, and the difference became statistically significant. This temporal shift suggests that disclosure tone evolved differently across ownership groups, reflecting changes in how sustainability-related signals were calibrated under evolving policy and informational conditions.

From a signaling theory perspective, this pattern may be associated with differences in signaling cost and signal credibility considerations across organizational types. As "Dual Carbon" related disclosure became more structurally central, as reflected in the keyword frequency, LDA, and co-occurrence network results, the informational importance of policy-related disclosure increased. Under such conditions, the perceived cost of overly optimistic or exaggerated disclosure may also increase, particularly when disclosure content is subject to greater scrutiny and evaluation. In signaling theory, credible signals

are typically associated with higher signaling costs(Connelly et al., 2011; Spence, 1973), as low-cost signals may be less informative and more easily imitated(Marquis et al., 2016). In this context, the observed tone moderation among non-SOEs may reflect an adjustment toward more measured and disciplined disclosure, which enhances signal credibility by reducing the risk of overstatement and improving consistency between symbolic communication and observable organizational conditions.

In contrast, the relatively stable sentiment scores observed among SOEs suggest a different signaling configuration. As organizations more closely embedded within state governance structures, SOEs may operate in an informational environment where their alignment with national policy objectives is more readily recognized by external stakeholders. This institutional embeddedness may reduce uncertainty regarding policy alignment, thereby lowering the need for substantial tonal adjustment as a signaling mechanism. In such cases, the expansion and structural prominence of "Dual Carbon" related disclosure, as demonstrated in the keyword frequency and network structure analyses, may provide sufficient signaling clarity. This pattern is consistent with signaling theory, which suggests that the necessity and intensity of signaling adjustments depend on the informational environment and the extent of uncertainty faced by signal receivers.

Differences in likely signal receivers may further contribute to variation in signaling strategies across ownership types(Connelly et al., 2011; Marquis & Qian, 2014). In particular, sustainability disclosure by SOEs may be more closely oriented toward institutional audiences, such as government authorities and regulatory bodies, within the broader policy governance framework. In this context, maintaining a consistently positive and policy-aligned disclosure tone may enhance the visibility of organizational alignment with national strategic priorities. By contrast, sustainability disclosure by non-SOEs may be interpreted primarily by market-oriented audiences, including investors and financial stakeholders, who rely on disclosure narratives to assess organizational positioning and future prospects. Under such conditions, adopting a more measured and disciplined tone may improve signal credibility and reduce uncertainty in stakeholder interpretation. These differences suggest that variation in disclosure tone across ownership types may reflect differences in signaling orientation and audience expectations within the evolving "Dual Carbon" policy environment.

In all, these findings suggest that ownership structure is associated with distinct signaling trajectories in corporate sustainability disclosure during the "Dual Carbon" transition. While both SOEs and non-SOEs expanded carbon-related disclosure and integrated climate-related concepts into central narrative structures, differences in sentiment evolution indicate variation in how disclosure tone was calibrated. These

patterns are consistent with signaling theory, which predicts that organizations adjust observable signal characteristics in response to differences in informational conditions, signaling costs, and stakeholder interpretation processes. These explanations should be understood as theory-informed interpretations of the observed divergence. While the findings are consistent with differences in institutional embeddedness, signaling cost, and likely signal audiences across ownership types, the present study does not directly test these causal mechanisms.

5.2.4. Theoretical Implications for Signaling Theory

This study provides several theoretical implications for signaling theory in the context of corporate sustainability disclosure under evolving policy environments. First, the findings suggest that sustainability disclosure signaling operates through multiple communicative dimensions, including narrative structure and disclosure tone. Previous signaling research has primarily focused on the presence, frequency, or quantity of disclosure as observable indicators of organizational attributes(Connelly et al., 2011; Spence, 1973). The results of this study indicate that signaling characteristics may also be reflected in how sustainability-related concepts are structurally integrated and positioned within disclosure narratives. The increased prominence of “Dual Carbon” related concepts in keyword frequency, topic modeling, and co-occurrence network structures suggests that structural visibility serves as an important component of signaling. At the same time, changes in sentiment tone indicate that signaling characteristics extend beyond disclosure volume and include qualitative aspects of narrative expression. These findings suggest that signaling processes in sustainability disclosure involve coordinated adjustments in both structural prominence and tonal expression.

Second, the sentiment evolution results provide insight into how disclosure tone may function as part of signaling calibration. In this study, while carbon-related disclosure expanded substantially during the observation period, sentiment scores exhibited a gradual moderation over time with remaining positive. From a signaling perspective, this pattern suggests that disclosure tone may reflect adjustments in how organizations communicate policy alignment under conditions of increasing informational importance and stakeholder attention. As disclosure content becomes more closely associated with policy evaluation and organizational positioning, the tone of communication may evolve toward greater precision and interpretability. This pattern is consistent with signaling theory, which suggests that observable signal characteristics may be refined to improve signal clarity and credibility in environments characterized by uncertainty and increased evaluation.

Third, the observed ownership-based differences in sentiment trajectories highlight the importance of organizational context in shaping signaling strategies. The divergence in tone evolution between SOEs and non-SOEs suggests that signaling characteristics may vary depending on differences in informational environments and likely signal audiences. These findings indicate that signaling processes in sustainability disclosure are not uniform across organizational types(Marquis & Qian, 2014). Instead, signaling strategies may reflect differences in institutional embeddedness, stakeholder expectations, and the informational role of disclosure narratives. This perspective extends signaling theory by illustrating how variations in organizational context may be associated with differences in observable signaling characteristics within policy-driven disclosure environments.

Taken together, these findings suggest that corporate sustainability disclosure under the "Dual Carbon" policy framework can be interpreted as a dynamic signaling process involving adjustments in both disclosure structure and narrative tone. By demonstrating how signaling characteristics evolve across structural and tonal dimensions and vary across organizational types, this study contributes to a more comprehensive understanding of signaling processes in sustainability disclosure. These insights extend signaling theory by highlighting the importance of narrative organization, tonal calibration, and organizational context in shaping how firms communicate policy alignment and sustainability positioning under conditions of evolving institutional expectations.

5.3 Integrated Interpretation: Structural Expansion and Sentiment Moderation

The preceding analyses demonstrate that corporate sustainability disclosure under the "Dual Carbon" policy framework evolved across multiple communicative dimensions. Structural indicators, including keyword frequency, theme prominence, and network centrality, consistently indicate increased attention toward Dual Carbon–related concepts over time. At the same time, sentiment analysis results show that disclosure tone remained positive but became more moderated, particularly within "Dual Carbon" semantic contexts. Taken together, these findings suggest that the evolution of corporate sustainability disclosure was characterized by a combination of expanding structural attention and moderating disclosure tone. This integrated pattern provides insight into how corporate sustainability reporting adapted as "Dual Carbon" concepts became more central within the broader disclosure environment.

The integrated finding of this study is not simply that carbon-related disclosure

increased or that disclosure tone declined. More importantly, these two patterns appeared together. The structural results show that "Dual Carbon" related concepts became more prominent, more thematically dominant, and more central within the disclosure network. At the same time, the sentiment results show that the tone associated with these concepts became more moderate. This combination suggests that corporate sustainability disclosure evolved through a dual adjustment process: companies made policy-related concepts more visible within the disclosure structure, while adopting a more cautious tone in expressing these concepts. This dual pattern provides the empirical basis for linking institutional alignment with signaling calibration.

5.3.1. Expansion of "Dual Carbon" Disclosure

The results of this study indicate a clear expansion in the structural prominence of "Dual Carbon" related disclosure within corporate sustainability communication. From 2019 to 2023, keyword coverage analysis shows that selected keywords appeared with increasing document coverage, indicating that these concepts received growing attention in corporate disclosure narratives. This trend is further supported by topic modeling results, in which climate-related themes, particularly those associated with emission reduction and carbon management strategies, became more prominent over time. These changes suggest that "Dual Carbon" concepts transitioned from peripheral references to central components of sustainability disclosure.

Evidence from co-occurrence network analysis provides further support for this structural shift. Over time, "Dual Carbon" concepts, particularly "Dual Carbon," "Carbon Neutrality," and "Carbon Peaking," emerged as central semantic hubs within the network structure of corporate sustainability disclosure. These concepts exhibited increasing connectivity and occupied structurally prominent positions, indicating their importance in shaping the overall organization of disclosure narratives. At the same time, concepts such as "Digitalization" and "Governance" functioned as structural connectors linking carbon-related clusters with broader sustainability and organizational themes. This network configuration suggests that "Dual Carbon" disclosure became a central organizing element, while digitalization and governance concepts facilitated its integration within the broader sustainability communication framework. Taken together, these patterns indicate that "Dual Carbon" concepts assumed a structurally central role, enhancing their visibility and interpretive importance within corporate sustainability disclosure.

In addition to broader keyword coverage and structural centrality indicators, the normalized frequency of "Dual Carbon" keywords provides a focused measure of

attention directed toward the “Dual Carbon” goal agenda. The observed increase in the normalized frequency of these policy-specific keywords suggests that Chinese-listed companies progressively integrated “Dual Carbon” related terminology into their sustainability disclosure. This increase in policy-specific keyword usage reinforces the broader structural evidence indicating that corporate sustainability disclosure evolved toward greater emphasis on carbon-related topics during the observation period.

Taken together, these structural changes indicate that corporate sustainability disclosure exhibited a clear expansion in attention toward Dual Carbon–related concepts. The increasing prominence, connectivity, and frequency of “Dual Carbon” disclosure suggest that carbon-related topics became more central to corporate sustainability communication. This expansion reflects a structural evolution in disclosure patterns, in which “Dual Carbon” concepts assumed a more visible and integrated role within corporate sustainability narratives.

5.3.2. Moderation of Disclosure Tone

While structural indicators demonstrate a clear expansion in the prominence of “Dual Carbon” disclosure, sentiment analysis reveals a contrasting pattern in the tonal characteristics of corporate sustainability communication. Across the study period, both comprehensive sentiment scores and “Dual Carbon” semantic window sentiment scores remained positive but exhibited a gradual decline in their mean values. This pattern indicates that although Chinese-listed companies increasingly incorporated “Dual Carbon” related concepts into their sustainability disclosure, the tone of such communication became more moderated over time. The coexistence of expanding structural attention and declining sentiment scores suggests that the evolution of disclosure involved adjustments in both thematic emphasis and tonal expression.

Further insight is provided by the semantic window sentiment analysis, which isolates tone specifically associated with “Dual Carbon” related disclosure contexts. Compared with comprehensive sentiment scores, semantic window sentiment scores were consistently lower, indicating that tone moderation was more pronounced within policy-specific disclosure segments. This difference suggests that sentiment moderation was not uniformly distributed across all sustainability disclosure content, but was particularly evident in disclosure directly associated with the “Dual Carbon” goal. As companies increasingly incorporated policy-specific terminology and carbon-related strategies into their sustainability communication, the associated tone became more measured, reflecting a shift toward more restrained narrative expression within policy-relevant disclosure contexts.

Ownership-based analysis provides additional perspective on the evolution of disclosure tone. The results indicate that non-SOEs exhibited a more pronounced decline in sentiment scores over time, while SOEs maintained relatively stable sentiment levels. This divergence suggests that tone moderation was more strongly expressed among non-SOEs during the period of increasing structural attention to "Dual Carbon" related disclosure. The temporal pattern further indicates that while both ownership groups expanded their structural engagement with "Dual Carbon" related topics, their tonal adjustments followed different trajectories. These findings suggest that the evolution of disclosure tone occurred alongside structural expansion but reflected heterogeneous patterns across organizational contexts.

Overall, the sentiment analysis results indicate that corporate sustainability disclosure underwent a process of tonal moderation during the same period in which structural attention toward "Dual Carbon" related concepts expanded. While carbon-related topics became more prominent, interconnected, and frequent within disclosure narratives, the associated tone became more moderated and restrained. This pattern suggests that the evolution of corporate sustainability disclosure involved coordinated changes across both structural and tonal dimensions, reflecting an increasingly calibrated approach to communicating policy-related sustainability information.

5.4 Limitations and Future Research

It should be acknowledged that there are some challenges when interpreting the findings of this study. First, this study examines corporate sustainability disclosure as a textual and communicative object. The analysis captures how firms organize, emphasize, connect, and frame sustainability-related information in their reports. However, these disclosure patterns should not be directly interpreted as evidence of actual carbon-reduction performance or substantive environmental outcomes. Sustainability disclosure may contain both substantive information and symbolic communication, especially under a strong policy context such as the "Dual Carbon" goal. Therefore, the findings of this study should be understood as disclosure-level evidence of corporate communication patterns, with further validation needed to examine the relationship between disclosed narratives and actual environmental practices.

5.4.1. Structural Evolution

Several limitations regarding structural evolution analysis can be seen in this study. First, the analysis focuses on corporate sustainability disclosure but not on firms' actual performance in undertaking sustainable responsibility. While textual disclosure provides

important insights into how firms demonstrate their response to institutional pressure and legitimacy concerns, it does not necessarily reflect substantive changes in operational practices (Marquis et al., 2016). Second, this study examines ownership-based heterogeneity by identifying different disclosure patterns between SOEs and non-SOEs, but it does not further conduct disaggregated analysis across industries. In the Chinese context, institutional pressure and policy influence may be transmitted unevenly across industries with different carbon intensities and regulatory exposure. The absence of such industry-based disaggregated analysis limits the ability to assess how industrial characteristics interact with institutional signals in shaping corporate disclosure strategies. Third, this study emphasizes China's institutional context and does not conduct cross-country comparative analysis. As disclosure regimes, policy timelines, and linguistic environments differ substantially across countries, the findings should be interpreted within the Chinese context. While cross-national comparison could provide additional insights into how other institutional backgrounds shape corporate sustainability disclosure, it would require a distinct comparative research design and further research.

Future research could address these limitations in several ways. One feasible direction is to conduct an industry-based analysis to explore heterogeneous institutional responses under the "Dual-Carbon" goal. Another option is to integrate disclosure analysis with quantitative environmental performance indicators, allowing for a closer examination of the relationship between symbolic disclosure and substantive action. This extension is especially important for distinguishing symbolic disclosure from substantive action. The present study shows how "Dual Carbon" related concepts became more visible and structurally central in sustainability disclosure, but it does not determine whether such disclosure corresponds to measurable improvements in carbon reduction, energy efficiency, or environmental performance. Future research may therefore combine disclosure-based indicators with firm-level carbon emission data, energy consumption metrics, ESG ratings, or third-party environmental evaluations. Such analysis would help examine whether structural expansion in disclosure is associated with substantive sustainability performance. Finally, as international climate-related regulations such as the EU's Carbon Border Adjustment Mechanism continue to evolve, future studies may further investigate how transnational institutional pressures interact with domestic climate policies to shape corporate disclosure behavior in emerging economies. Our keyword frequency analysis already provides initial evidence that the document coverage of "Carbon Border Adjustment Mechanism have become statistically significant in recent years.

5.4.2. Sentiment Evolution

While this study provides new insights into the tonal evolution of corporate sustainability disclosure under the "Dual Carbon" policy framework, several limitations associated with sentiment analysis should be acknowledged.

First, the sentiment analysis in this study relies on a lexicon-based approach using a domain-specific financial sentiment dictionary. Although this method provides a systematic and transparent way to measure disclosure tone, lexicon-based sentiment analysis has inherent limitations in capturing contextual nuance. Specifically, the method identifies sentiment polarity based on predefined word classifications but cannot fully account for semantic context, linguistic ambiguity, or sentence-level meaning. As a result, certain expressions that appear neutral or positive in isolation may carry different interpretive implications within specific disclosure contexts. Future research may further extend the present framework by comparing lexicon-based and machine learning-based approaches. AI-assisted methods may also be used to identify strategic framing, exaggerated claims, or possible greenwashing in sustainability disclosure under policy transition. Such an extension would help evaluate whether moderated or positive disclosure tone reflects careful communication, symbolic alignment, or substantive environmental commitment.

Second, the semantic window extraction method used in this study involves defining a fixed word range around "Dual Carbon" keywords to isolate policy-specific disclosure tone. While the ±75-word window was empirically informed by sentence length distribution analysis, this approach remains an approximation of contextual boundaries. Variations in sentence structure, disclosure style, and document formatting may influence the extent to which the selected window fully captures relevant semantic context. Future studies may explore alternative methods for contextual extraction, including sentence-level or paragraph-level segmentation, to improve the accuracy of policy-specific sentiment measurement.

Third, sentiment analysis measures the tonal characteristics of disclosure but does not directly reflect the substantive implementation of sustainability practices. Positive or moderated disclosure tone may reflect communication strategies, institutional alignment, or signaling considerations, but it does not necessarily provide direct evidence of operational performance or actual carbon reduction outcomes. Future research may integrate sentiment analysis with objective environmental performance indicators, such as carbon emission data, energy consumption metrics, or third-party environmental ratings, to examine the relationship between disclosure tone and substantive sustainability

performance.

Finally, this study primarily examines sentiment evolution at the aggregate level, focusing on overall trends across the disclosure corpus. While ownership-based heterogeneity analysis provides insight into differences between SOEs and non-SOEs, the analysis does not explore variation in disclosure tone across industries. Firms in different industries may face distinct regulatory pressures, transition risks, and disclosure expectations related to the "Dual Carbon" goal, which may influence how disclosure tone evolves over time. Future research may extend this analysis by examining industry-level differences in sentiment evolution, as well as firm-level variation in tone adjustment strategies. Such analyses may provide deeper insight into the heterogeneous dynamics underlying corporate sustainability disclosure under evolving institutional and policy environments.

In summary, these future research directions from both structural and sentimental dimensions should be understood as extensions of the main findings of this dissertation. The finding of structural expansion suggests the need to examine whether increased disclosure visibility corresponds to substantive environmental action. The finding of sentiment moderation suggests the need to investigate how firms manage credibility, caution, and strategic framing in sustainability communication. Future studies that combine text analysis, environmental performance indicators, AI-assisted disclosure evaluation, and interview-based evidence may further clarify the relationship between disclosure evolution and actual organizational response under climate policy.

Chapter 6
Conclusion

This chapter summarizes the main findings of this study and presents the overall conclusions regarding the structural and sentiment evolution of corporate sustainability disclosure among Chinese-listed companies under the “Dual Carbon” goal. Building on the empirical results presented in Chapter 4 and the interpretive analysis developed in Chapter 5, this chapter provides a comprehensive synthesis of how sustainability disclosure evolved during the period from 2019 to 2023.

The chapter is organized into four sections. Section 6.1 summarizes the structural and sentiment evolution of corporate sustainability disclosure and directly addresses the research questions of this study. Sections 6.2 and 6.3 present conclusions under institutional and signaling contexts, respectively, highlighting the theoretical significance of the findings. Section 6.4 presents the overall conclusions and research contributions, and discusses implications and potential future applications. Through this synthesis, the chapter clarifies the broader significance of the study and its contribution to understanding corporate sustainability disclosure in the context of major climate policy transformation.

6.1 Structural and Sentiment Evolution of Corporate Sustainability Disclosure

This study investigates how the sustainability reporting of Chinese-listed companies has evolved structurally and sentimentally under the “Dual Carbon” goal from 2019 to 2023. Applying word frequency analysis, LDA topic modeling, co-occurrence network analysis, and sentiment analysis, the study provides a comprehensive perspective on changes in narrative priority, thematic organization, semantic connectivity, and disclosure tone within corporate sustainability disclosure. The results indicate that Chinese-listed companies adjusted their sustainability communication in response to the evolving policy environment, with observable changes in both the structural organization and tonal characteristics of disclosure. The main finding of this dissertation is that corporate sustainability disclosure under the “Dual Carbon” goal evolved through structural expansion accompanied by sentiment moderation. Structural expansion refers to the increased prominence, thematic dominance, and semantic centrality of “Dual Carbon”

related concepts in sustainability disclosure. Sentiment moderation refers to the gradual movement toward a more measured tone in both comprehensive disclosure and "Dual Carbon" related disclosure. Together, these two patterns provide the central answer to the main research question of this study. The findings indicate that Chinese-listed companies' sustainability reporting has experienced substantial structural and sentimental changes under the "Dual-Carbon" goal framework in four key respects.

First, the narrative priority of corporate disclosure expanded from universal sustainability concepts toward a clear emphasis on carbon-related policy objectives. Carbon-related keywords experienced a statistically significant rise after 2020. The increased attention to terms regarding measurement and execution orientation was observed as well. This trend suggests a shift toward more concrete and accountable climate disclosure among Chinese-listed companies, reflecting growing attention to carbon governance, emission management, and policy alignment in corporate sustainability communication.

Second, the thematic organization of sustainability disclosure among Chinese-listed companies evolved significantly, reflecting a shift in the underlying narrative logic of corporate reporting. The narrative logic of corporate sustainability disclosure evolved from a traditional pollution-control orientation to a climate strategy and emission reduction framework. LDA Topic modeling results show that Climate & Emission Strategy emerged as the most prominent thematic lineage, while Resource Utilization & Pollution Control declined sharply and even lost semantic coherence in 2022. This pattern indicates that pollution-related concerns were increasingly absorbed into carbon-centered climate narratives but not remaining independent organizing logic. These findings suggest that Chinese-listed companies progressively reorganized their disclosure priorities, aligning sustainability communication more closely with climate policy objectives and long-term emission reduction strategies.

Third, the structural integration of corporate sustainability disclosure among Chinese-listed companies strengthened through changes in semantic connectivity and keyword centrality. Co-occurrence network analysis reveals that "Dual Carbon" and "New Energy" functioned as central hubs, while keywords such as "Digitalization" and "Governance" acted as key connectors linking climate strategy, technological pathways, and managerial frameworks. This suggests that digital infrastructure and governance mechanisms have become closely integrated components for organizing and legitimizing climate-oriented disclosure. The increasing centrality of carbon-related concepts within the semantic network indicates that Chinese-listed companies incorporated climate-related topics more deeply into the structural organization of sustainability reporting, reinforcing their

importance within corporate disclosure narratives.

Fourthly, the results reveal a clear evolution in disclosure tone among Chinese-listed companies. Sentiment analysis indicates that sustainability disclosure maintained an overall positive tone from 2019 to 2023, while sentiment scores exhibited a gradual decline over time. Both comprehensive sentiment scores and "Dual Carbon" semantic window sentiment scores remained positive but showed consistent moderation across the study period. This pattern suggests that Chinese-listed companies increasingly adopted a more measured and disciplined tone when communicating carbon-related commitments. The observed tone moderation was particularly evident in disclosure segments directly associated with the "Dual Carbon" goal, indicating greater caution and precision in policy-related communication. Ownership-based analysis further reveals heterogeneity in tonal adjustment, with non-state-owned enterprises exhibiting a more pronounced decline in sentiment scores compared with state-owned enterprises. This divergence suggests that Chinese-listed companies adapted their disclosure tone in different ways, reflecting differences in institutional positioning and communication strategies.

Overall, the findings indicate that the sustainability reporting of Chinese-listed companies underwent coordinated structural and tonal evolution under the "Dual Carbon" goal framework. Structural expansion is reflected in the increased prominence, thematic centrality, and semantic integration of carbon-related concepts, while tonal moderation is reflected in the gradual shift toward more measured disclosure tone. These patterns suggest that Chinese-listed companies reorganized both the content and sentiment preference of sustainability disclosure, aligning corporate communication more closely with the evolving policy environment and institutional expectations associated with China's climate transition.

6.2 Conclusion under Institutional Context

This study shows that the "Dual Carbon" goal was associated with substantial changes in the institutional environment within which Chinese-listed companies construct and present sustainability disclosure. From 2019–2023, corporate sustainability reporting exhibited systematic structural and tonal adjustments that are consistent with institutional adaptation under strengthened policy expectations. The findings indicate that the evolution of sustainability disclosure during this period reflects a process of institutional realignment, in which firms recalibrated both narrative priorities, logics and expressive tone in response to a changing regulatory and normative landscape.

At the structural level, the results show that Chinese-listed companies reorganized sustainability disclosure around carbon-related policy objectives. Carbon-related

keywords displayed a significant rise following 2020, and climate-oriented themes gained prominence in topic modeling results. Co-occurrence network analysis further reveals that “Dual Carbon,” “Carbon Neutrality,” and “Carbon Peaking” assumed central positions within the semantic structure of disclosure, while concepts such as “Digitalization” and “Governance” facilitated their integration into broader organizational narratives. These patterns suggest that the “Dual Carbon” goal operated as a prominent institutional signal and was associated with a shift in what constitutes legitimate and salient sustainability disclosure. Instead of representing individual additions, carbon-related concepts became embedded within the core organizational logic of reporting, indicating a redesign of narrative structure under institutional pressure.

Beyond structural reorganization, the study also identifies a consistent moderation of disclosure tone. Although sustainability disclosure remained generally positive, both comprehensive sentiment scores and “Dual Carbon” semantic window sentiment scores exhibited a gradual decline across the study period. This tonal moderation occurred alongside the expansion of carbon-related disclosure, indicating that institutional adaptation involved adjustments in expressive discipline as well as thematic emphasis. In the context of heightened policy scrutiny and growing accountability expectations, Chinese-listed companies appear to have adopted a more measured and calibrated tone when articulating carbon-related commitments. Such adjustments suggest that institutional alignment may be reflected in how disclosure is framed and communicated, not solely in what is disclosed.

Ownership-based heterogeneity further enriches this institutional interpretation. Differences between SOEs and non-SOEs indicate that the degree of institutional embeddedness shapes disclosure strategies. SOEs, as organizations more closely affiliated with state policy structures, exhibited relatively stable sentiment trajectories and strong incorporation of policy-framed vocabulary. Non-SOEs, by contrast, displayed more pronounced tonal moderation over time. These patterns highlight that institutional environments do not produce uniform responses; instead, organizational position within political and administrative hierarchies influences how sustainability disclosure evolves under policy-driven transformation.

Taken together, the findings suggest that the “Dual Carbon” goal was associated with a multidimensional evolution of corporate sustainability disclosure among Chinese-listed companies. Structural expansion of carbon-related themes and calibrated moderation of disclosure tone jointly reflect an ongoing process of institutional adaptation. This study therefore contributes to institutional research by demonstrating that major climate policy initiatives in emerging economies can be associated with systematic changes in both the

organization and sentiment preference of corporate sustainability narratives.

6.3 Conclusion under Signaling Context

This study indicates that the evolution of sustainability disclosure among Chinese-listed companies from 2019–2023 is consistent with patterns of strategic communication under a changing policy environment. The observed expansion of carbon-related disclosure, reflected in the increased coverage, frequency, and structural prominence of "Dual Carbon," "Carbon Neutrality," and "Carbon Peaking," suggests that sustainability reporting served as an important channel through which firms articulated their alignment with national climate polices. LDA Topic modeling results further show that climate-related themes became increasingly dominant, while co-occurrence network analysis reveals that carbon-related concepts assumed central positions within the semantic structure of disclosure. These patterns indicate that Chinese-listed companies progressively enhanced the visibility and prominence of carbon-related topics within sustainability reporting, which is consistent with the interpretation that disclosure content functions as a mechanism for communicating organizational positioning within evolving policy and regulatory contexts.

Beyond structural expansion, the results also indicate that disclosure tone evolved in a manner consistent with signaling considerations related to credibility and interpretability. Although sustainability disclosure remained generally positive across the study period, both comprehensive sentiment scores and "Dual Carbon" semantic window sentiment scores exhibited a gradual decline. This pattern suggests that Chinese-listed companies adopted increasingly measured and calibrated disclosure tone when communicating carbon-related commitments. In signaling theory, credibility is closely associated with the perceived reliability and verifiability of communicated information. Excessively optimistic or generalized disclosure may be subject to greater scrutiny or skepticism, particularly under heightened policy attention. In this context, the observed moderation of disclosure tone is consistent with the interpretation that firms adjusted their expressive strategies to maintain credibility and clarity in communicating sustainability commitments. These findings suggest that disclosure tone, alongside disclosure volume and structural prominence, constitutes an important dimension through which signaling processes may be manifested in sustainability reporting.

Ownership-based differences further highlight heterogeneity in signaling strategies across organizational contexts. The results indicate that SOEs maintained relatively stable sentiment trajectories while exhibiting strong structural incorporation of policy-related vocabulary. In contrast, non-SOEs exhibited more pronounced moderation in disclosure

tone over time. These differences are consistent with the interpretation that Chinese-listed companies operate within heterogeneous signaling environments characterized by distinct institutional affiliations and audience expectations. For SOEs, sustainability disclosure may serve as a channel for communicating alignment with government policy priorities, given their closer integration within state policy and administrative structures. For non-SOEs, sustainability disclosure may function more prominently as a communication mechanism directed toward investors and market participants, where disclosure credibility and interpretability are particularly important. These patterns suggest that differences in organizational positioning and audience orientation may be reflected in variation in signaling strategies, including both disclosure emphasis and tone calibration.

Overall, the findings indicate that the structural expansion and tonal moderation of sustainability disclosure among Chinese-listed companies are consistent with signaling interpretations of corporate communication under policy transition. The increasing prominence of carbon-related disclosure and the concurrent moderation of disclosure tone suggest that sustainability reporting evolved as a multidimensional signaling channel, encompassing both the visibility of policy-related commitments and the calibration of communicative tone. These results contribute to signaling theory by demonstrating that signaling processes in sustainability disclosure may operate simultaneously through structural prominence and tonal expression. In the context of China's "Dual Carbon" goal, sustainability disclosure appears to function as an important medium through which Chinese-listed companies communicate organizational alignment, interpret policy expectations, and position themselves within an evolving institutional and informational environment.

6.4 Overall Conclusion and Research Contributions

6.4.1. Main Conclusions

The overall conclusion of this dissertation is that Chinese-listed companies' sustainability disclosure experienced a multidimensional evolution under the "Dual Carbon" goal. This evolution was characterized by the coexistence of structural expansion and sentiment moderation. Empirically, firms increased the visibility and structural importance of carbon-related concepts in their disclosure narratives. At the same time, the tone of disclosure became more measured, especially in "Dual Carbon" related semantic contexts. Theoretically, this pattern suggests that corporate disclosure evolution under climate policy can be understood as a combined process of institutional alignment

and signaling calibration.

With respect to structural evolution, the findings indicate a clear expansion in the prominence of carbon-related disclosure among Chinese-listed companies. Carbon-related keywords displayed a statistically significant rise following the introduction of the "Dual Carbon" goal. Topic modeling results show that Climate & Emission Strategy emerged as the most prominent thematic lineage, while Resource Utilization & Pollution Control declined in relative salience. Co-occurrence network analysis further demonstrates that "Dual Carbon," "Carbon Neutrality," and "Carbon Peaking" occupied central positions within the semantic structure of corporate sustainability disclosure. At the same time, "Digitalization" and "Governance" functioned as important structural connectors, facilitating the integration of carbon-related topics into broader managerial and organizational narratives. These findings indicate that carbon-related concepts became central organizing elements in the sustainability reporting of Chinese-listed companies.

Regarding sentiment evolution, the analysis reveals a consistent pattern of tone moderation. Although sustainability disclosure remained generally positive, both comprehensive sentiment scores and "Dual Carbon" semantic window sentiment scores exhibited a gradual decline from 2019–2023. This pattern suggests that while Chinese-listed companies increasingly emphasized carbon-related topics, they communicated such commitments in a progressively more measured and calibrated tone. Ownership-based analysis further indicates that SOEs maintained relatively stable sentiment trajectories, whereas non-SOEs demonstrated a more pronounced decline in sentiment scores. These differences suggest heterogeneous patterns of tone adjustment across ownership structures.

Above, the results show that the sustainability reporting of Chinese-listed companies experienced a multidimensional evolution under the "Dual Carbon" goal. Carbon-related topics became structurally central within corporate sustainability narratives, while disclosure tone exhibited gradual moderation. These structural and tonal developments together characterize the transformation of sustainability disclosure among Chinese-listed companies during a period marked by intensified climate policy attention.

6.4.2. Research Contributions

This study makes several important contributions to the empirical, theoretical, and interdisciplinary understanding of corporate sustainability disclosure in the context of major climate policy transitions. By examining sustainability reporting among Chinese-listed companies from 2019–2023, the study provides new evidence on how disclosure

evolves structurally and sentimentally under a nationally coordinated climate and energy governance framework.

From an empirical perspective, this study contributes by providing a comprehensive and multidimensional analysis of sustainability disclosure evolution. Existing research has primarily focused on disclosure quantity or topic coverage, while relatively limited attention has been given to the structural organization and expressive tone of disclosure narratives. This study extends empirical literature by integrating keyword coverage analysis, topic modeling, co-occurrence network analysis, and sentiment analysis within a unified analytical framework. The results demonstrate that sustainability disclosure among Chinese-listed companies evolved through the increasing structural prominence of carbon-related concepts and concurrent moderation of disclosure tone. By documenting both structural expansion and tonal moderation, the study provides a more complete empirical account of how sustainability disclosure develops in response to evolving climate policy environments.

This study also contributes by providing detailed empirical evidence from an emerging economy undergoing rapid climate and energy policy development. While much of the sustainability disclosure literature has focused on developed economies, empirical evidence from emerging markets remains comparatively limited. By analyzing sustainability reporting among Chinese-listed companies under the “Dual Carbon” goal, this study offers insights into how corporate disclosure evolves within a policy-driven institutional context characterized by strong government coordination. These findings contribute to a broader understanding of sustainability disclosure dynamics beyond conventional market-driven settings.

From a methodological perspective, this study contributes by developing an integrated analytical approach for examining disclosure evolution across multiple textual dimensions. The methodological contribution does not lie only in combining several text analysis techniques, but in linking each technique to a specific analytical dimension required by the research problem. Keyword coverage analysis captures changes in narrative priority by identifying whether policy-related concepts became more visible in corporate disclosure. LDA topic modeling captures changes in thematic organization by examining how disclosure topics and semantic lineages evolved over time. Co-occurrence network analysis captures changes in semantic composition by identifying whether carbon-related concepts moved toward more central positions within the disclosure network. Sentiment analysis captures changes in expressive tone by examining how companies framed sustainability and “Dual Carbon” related content. A single method would not be sufficient to capture these dimensions together. Therefore, the integrated

approach provides a systematic way to examine how disclosure evolves structurally and sentimentally under a changing policy environment.

From a theoretical perspective, this study contributes to institutional theory and signaling theory by demonstrating how sustainability disclosure can be interpreted as a multidimensional symbolic practice. In relation to institutional theory, the findings show that structural reorganization and tone moderation in sustainability disclosure are consistent with patterns of institutional adaptation under evolving policy expectations. Sustainability reporting among Chinese-listed companies reflects adjustments in narrative structure, thematic emphasis, and communicative tone, which align disclosure practices with emerging institutional priorities.

In relation to signaling theory, this study highlights the importance of disclosure structure and tone as interpretive dimensions of signaling processes. The increasing prominence of carbon-related concepts and the calibrated moderation of disclosure tone suggest that sustainability reporting may function as a channel through which firms communicate alignment with evolving policy and informational environments. These findings extend signaling theory by illustrating how signaling processes may be reflected in both the structural organization and tonal expression of corporate disclosure. In particular, the finding of sentiment moderation extends the signaling interpretation by showing that credibility-oriented signaling may appear through a more measured disclosure tone. This finding suggests that firms may strengthen signal credibility by increasing the visibility of policy-related concepts and by avoiding overly optimistic language under policy-sensitive conditions.

From a Knowledge Science perspective, this study also provides an additional contribution by treating corporate sustainability disclosure as a structured and evolving system of knowledge representation. In line with the Knowledge Science emphasis on knowledge creation, accumulation, and utilization, this study conceptualizes disclosure structure as an operational knowledge structure composed of narrative priority, narrative logic, and semantic composition, while also incorporating disclosure tone as an important expressive dimension. On this basis, the study develops an analytical framework for examining how such knowledge structures evolve over time under a major policy context. The findings further show that the evolution of disclosure knowledge is shaped by institutional pressure and information asymmetry, as firms reorganize narrative emphasis, semantic relationships, and disclosure tone in response to changing regulatory expectations and signaling needs. In this sense, the present study extends sustainability disclosure research by offering a Knowledge Science lens through which corporate disclosure can be understood as a dynamic process of knowledge organization,

adjustment, and communication.

In all, this study advances the sustainability disclosure literature by providing a multidimensional interpretive framework for understanding how corporate disclosure evolves structurally and sentimentally in response to major climate policy transitions. By focusing on Chinese-listed companies under the "Dual Carbon" goal, the study enriches empirical, methodological, theoretical, and interdisciplinary understanding of sustainability disclosure evolution within emerging economy contexts.

6.4.3. Implications and Future Applications

The implications and future applications of this study are directly connected to the two main findings of structural expansion and sentiment moderation. These findings have several important implications for academic research, policy evaluation, and the practical interpretation of corporate sustainability disclosure. By examining structural and sentiment evolution in sustainability reporting among Chinese-listed companies from 2019–2023, this study provides insights into how corporate disclosure develops under conditions of intensified climate or energy policy attention.

From an academic perspective, this study highlights the importance of examining sustainability disclosure as a multidimensional phenomenon encompassing structural organization and communicative tone. The results demonstrate that disclosure evolution may be reflected in changes in thematic prominence, semantic connectivity, and sentiment expression. These findings suggest that future research may benefit from combining structural and sentiment-based analytical approaches to capture a more comprehensive picture of disclosure dynamics. In addition, the analytical framework developed in this study may be applied to other policy contexts, enabling comparative analysis across different regulatory environments, policy domains, or national settings.

From a policy design perspective, the findings provide insight into how Chinese-listed companies adjust sustainability disclosure in the context of major climate or energy policy initiatives. The increasing prominence of carbon-related concepts in sustainability reporting indicates that corporate disclosure reflects evolving policy priorities. At the same time, the moderation of disclosure tone suggests that firms communicate climate-related commitments with increasing communicative discipline. These patterns may help policymakers and regulatory bodies better understand how corporate disclosure evolves alongside policy development, and may inform the design of disclosure standards, reporting guidelines, and regulatory frameworks related to climate governance.

From a practical perspective, the results may also be relevant for investors, analysts, and other stakeholders who rely on sustainability disclosure to evaluate corporate climate-

related positioning. The structural prominence of carbon-related topics and the evolution of disclosure tone provide interpretive signals that may assist stakeholders in assessing how firms present their sustainability commitments. Understanding these structural and tonal patterns may enhance the interpretation of corporate sustainability disclosure in contexts where climate policy plays an increasingly prominent role.

Finally, this study opens several avenues for future research. Future studies may extend the analytical framework to examine industry-level variation, cross-country comparisons, or longer time horizons. Firm-level analysis may also provide additional insights into how disclosure structure and tone vary across organizational characteristics and institutional environments. In addition, future research may explore how sustainability disclosure evolution relates to broader organizational, market, or regulatory developments, thereby contributing to a deeper understanding of sustainability communication in evolving policy contexts. In detail, it may further extend this dissertation by linking disclosure-level findings with actual performance and qualitative evidence. In particular, carbon emission data, energy consumption indicators, ESG ratings, AI-assisted detection of symbolic disclosure, and interviews with report preparers or managers may help examine whether disclosure evolution corresponds to substantive organizational response. Such extensions would further clarify the relationship between corporate sustainability communication and actual climate-related action under policy transition.

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Appendices

Appendix A: 21 policy-relevant keywords

Keyword	2019	2020	2021	2022	2023
Green	13058	16724	34081	55042	87196
Dual Carbon	0	35	2981	5876	8287
Carbon Neutrality	20	905	4393	5031	6336
Carbon Peaking	0	401	2228	3003	3672
Environmental Governance	290	338	494	810	1169
Environmental Protection	5101	5744	8471	13574	19118
Policy	5707	7097	11275	16267	25409
Environmentally Friendly	15459	17821	24375	35683	53231
Environmental Policy	36	42	62	104	145
Green Development	1955	2474	4524	7537	11835
Sustainable Development	8359	8466	18258	30597	59196
National Policy	208	283	437	652	1101
National Strategy	488	521	1031	1377	2194
Developmental Goal	338	445	610	884	1368
Emission	7497	9298	16278	26930	43750
Carbon Emissions	566	854	2755	5108	8974
Emission Volume	2052	2461	3864	6124	10295
Emission Reduction	3354	3930	6796	10035	14589
Carbon Tariff	0	0	2	13	76
CBAM/Carbon Border Adjustment Mechanism	0	0	0	0	0
Total valid words	7771922	9350625	13970925	20354283	30314236

Appendix B.1: Topic keyword distribution of 2019

T0	Financial Services	Insurance	Epidemic	Customer Experience	Party Building	AML	Service Branch
T1	Strategic Issues	Governance	Waste	GHG	Emission Volume	Employment	Employees
T2	Power	Construction	Construction	Railway	Power Generation	Nuclear Power	Unit
T3	Medical Science	Biological	Hospital	Pharmaceuticals	Medicine	Pharmacy Industry	Inspection
T4	Wastewater	Exhaust Gas	Port	Mining Area	Sewage	Mining	Chemical Industry
T5	Food	Food Safety	Logistics	Home Furnishing	Express Delivery	Experience	Aviation
T6	Automotive	Factory	New Energy	Epidemic	Communication	Customer	Equipment

Appendix B.2: Topic keyword distribution of 2020

T0	Automotive	Factory	Customer	Networked (IoT)	Digitalization	Software	Microelectronics
T1	Construction	Party Building	Power	Gas	Construction (Work)	Water Affairs	Real Estate
T2	Governance	Waste	Strategic Issues	GHG	Emission Volume	Nuclear Power	Employees
T3	Financial Services	Insurance	Experience	Strategic Issues	Empowerment	SMEs	Green Finance
T4	Logistics	Food	Railway	Transportation	Port	Agriculture	Food Safety
T5	Mining	Coal	Chemical Industry	China Tong	Mining Area	Mining Industry	Gold
T6	Biological	Medicine	Medical Science	Pharmacy Industry	Pharmaceuticals	Pharmacy (Store)	Public (Lao Bai Xing)

Appendix B.3: Topic keyword distribution of 2021

T0	New Materials	Workshop	Coal	New Energy	Emission Volume	Occupational Disease	Sewage
T1	Governance	Power	Construction	Construction	Power Generation	Nuclear Power	Railway
T2	Food	Logistics	Factory	Agriculture	Customer	Home Furnishing	Hotel
T3	Green Finance	Financial Services	AML	Insurance	Service Branch	Inclusive Finance	Port
T4	Biological	Medicine	Drug	Pharmaceuticals	Vaccine	Patient	Clinical
T5	Governance	Strategic Issues	Information Security	Waste	GHG	Climate Change	Electric
T6	Party History	Xi Jinping	Long-term	Equipment	Politics	Party Organization	Poverty Alleviation

Appendix B.4: Topic keyword distribution of 2022

T0	Governance	GHG	Climate Change	PV (Photovoltaics)	Reporting	Biological	Chemicals
T1	Wind Power	Power Generation	Electrical	Shipbuilding	Chemical Industry	Mining Industry	Mining
T2	Biological	Medicine	Drug	Clinical	Pharmaceuticals	Patient	Vaccine
T3	Green Finance	Financial Services	Cybersecurity	Logistics	Inclusive Finance	Software	Insurance
T4	Food	Agriculture	Food Safety	Gas	Breeding	Water Affairs	Logistics
T5	Construction	Construction (Work)	Hotel	Youth	Aviation	Beautiful	STAR Market
T6	Automotive	Equipment	Customer	Microelectronics	Chip	Semiconductor	Automation

Appendix B.5: Topic keyword distribution of 2023

T0	Food	Chemistry	Chemical Industry	Customer	Agriculture	Food Safety	Special Paper
T1	Aerospace	Automotive	Mining Industry	Mining	Steel	Mining Area	Gold
T2	Governance	Chemicals	Climate	Battery	Chip	Co-creation	Automotive
T3	Wind Power	Construction (Work)	Natural Gas	Energy Storage	Transportation	Youth	SASAC
T4	Electrical	Shipbuilding	Port	Shipping	Tire	Maritime	Ningbo
T5	Construction	Green Finance	Financial Services	Cybersecurity	Data Security	Model	AML
T6	Medicine	Drug	Pharmaceuticals	Clinical	Patient	Vaccine	Pharmacy Industry

Appendix C.1: Co-occurrence network keyword Degree centrality (2019 vs 2023)

Keyword	2019	2023
Dual Carbon	0	15
Carbon Peaking	0	13
Carbon Neutrality	1	13
Digitalization	11	17
Climate Change	11	16
Energy Storage	6	11
Green Finance	6	11
Photovoltaics	9	13
Carbon Emissions	8	12
GHG	7	11
Emission Reduction	12	14
Wind Power	8	10
Governance	7	9
Data Security	3	5
New Energy	14	14
Env. Governance	6	5
IT	5	4
Cybersecurity	7	3
Insurance	9	4

Appendix C.2: Co-occurrence network keyword weighted and normalized degree (2019 vs 2023)

Keyword	Raw 2019	Norm 2019	Raw 2023	Norm 2023
Carbon Neutrality	2	0.19	3929	172.4
Carbon Peaking	0	0	3315	145.46
Emission Reduction	201	19.46	2964	130.06
Photovoltaics	131	12.68	2255	98.95
GHG	159	15.39	2212	97.06
Dual Carbon	0	0	2148	94.25
Climate Change	114	11.04	2035	89.29
New Energy	130	12.58	2020	88.64
Carbon Emissions	50	4.84	1597	70.07
Energy Storage	37	3.58	1263	55.42
Wind Power	74	7.16	863	37.87
Digitalization	29	2.81	759	33.3
Green Finance	11	1.06	450	19.75
Cybersecurity	34	3.29	436	19.13
Data Security	18	1.74	400	17.55
Governance	24	2.32	311	13.65
IT	30	2.9	192	8.42
Insurance	24	2.32	62	2.72
Env. Governance	18	1.74	55	2.41