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Insight into Policy Structure and Key Characteristics of China's Low-Carbon Policy System: Based on Text Mining Method

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Abstract: Developing a comprehensive low-carbon policy system is essential for China to achieve both the "carbon peak" and "carbon neutrality" milestones, significantly contributing to sustainable development. However, research on low-carbon policy predominantly emphasizes policy tools, implementation paths, and implementation effects, neglecting the comprehensive analysis of the systemic structure and evolutionary traits of such policy frameworks. To address the above problems, this study elucidates the structure, evolutionary stages, and key characteristics of low-carbon policies issued from 2007 to 2022 through text mining methods. Results show that: (1) China's low-carbon policies progress through three distinct stages: initial exploration stage (2007–2015), accelerated advancement stage (2016–2019), and comprehensive implementation stage (2020–2022). (2) China's "1 + N" policy system covers a broad spectrum of sectors, including energy, industry, construction, transportation, and finance, ensuring comprehensive coverage across various domains of policy. (3) The policy spotlight has progressively shifted from environmental protection to low-carbon development, emphasizing carbon market construction and innovative development. According to the key findings, this study provides recommendations that encompass crucial aspects such as accelerating technological innovation, strengthening carbon market mechanisms, and promoting green finance. Overall, the textual analysis of the low-carbon policy system in this study underscores the significance of policy structural coordination and evolution, offering insights for shaping China's future roadmap in advancing low-carbon objectives.

Keywords: low-carbon policy; sustainable development; text mining method; policy system; policy structure; policy characteristics; policy stage

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1. Introduction

The escalating global concerns over climate change and sustainable development have prompted 151 countries worldwide to propose carbon neutrality goals. These countries collectively represent 92% of the global GDP (measured by purchasing power parity), 89% of the global population, and contribute to 88% of global carbon emissions [1]. Governments across the globe are actively formulating policies to reduce carbon emissions, making effective climate policies a focal point of global attention [2]. For example, Germany has implemented the Federal Climate Protection Act, emphasizing energy system transformation and renewable resource development. By 2030, Germany aims to reduce total greenhouse gas emissions by at least 55% compared to 1990 levels, and achieve carbon neutrality by 2050. The United Kingdom's Ten Point Plan for a Green Industrial Revolution outlines decarbonization actions across ten key industries, focusing on low-carbon technology research and key carbon emission sectors. The United States' Long-Term Strategy to reach net-zero emissions by 2050 integrates climate governance into its core diplomatic and national security agendas, promoting clean energy technology innovation and reducing emissions across

various sectors. Japan's 2050 Carbon Neutral Green Growth Strategy emphasizes green technology development in industries like offshore wind, nuclear power, and hydrogen. In comparison, China's policies, such as the Opinions on Fully and Accurately Implementing the New Development Philosophy for Carbon Peak and Carbon Neutrality and the Action Plan for Carbon Dioxide Peaking Before 2030, outline sector-specific strategies for energy, industry, transportation, and urban construction. While China has made significant strides, there remain areas for improvement in top-level legislative constraints, long-term planning, and strategic actions compared to major developed countries [2]. Between 1978 and 2020, China's annual CO_2 emissions surged from 1.49 billion tons to 10.67 billion tons, reflecting an annual growth rate of 4.80%. This significant increase positioned China as the world's largest emitter of CO_2 after 2006. By 2020, China's CO_2 emissions surpassed the combined total emissions of the United States, India, Russia, Japan, and Germany [3]. In 2020, China's total energy consumption reached 4.98 billion tons of standard coal, equivalent to 9.9 billion tons of carbon dioxide emissions, constituting 30.9% of the global emissions [4]. Despite substantial emission reductions by developed countries, mitigating global warming remains unattainable without China's concerted efforts [5]. Therefore, China's low-carbon policies hold global significance and are likely to be pivotal in achieving international climate goals [6].

In September 2020, China explicitly set the "carbon peak" target for 2030 and the "carbon neutrality" target for 2060. Against this background, the effectiveness and evolutionary characteristics of China's climate policy system around carbon reduction goals have attracted much attention from academics and policymakers. However, the rapid issuance of numerous policies by the government in recent years has made it challenging to discern the integrity and evolutionary features of the policy system, potentially leading to policy redundancy and confusion, thereby hindering the comprehensive achievement of carbon reduction targets. Given this scenario, this study aims to comprehensively analyze and delineate the structure and policy evolution of China's climate policy system formulated around carbon reduction goals from 2007 to 2022, providing scientific support for future low-carbon policy formulation and optimization. Therefore, the research firstly focuses on the policy coverage and policy hierarchy of China's low-carbon policy system, to reveal the overall structure and organizational form of the policy system, and secondly explores the evolution process, development trajectory, and changes in policy priorities of China's low-carbon policies, to understand the evolution mode and characteristics of policies at different stages.

Existing research on low-carbon policies focuses on policy tools, implementation paths, and implementation effects. Content analysis was mainly used to analyze the type of distribution and use of policy tools in low-carbon policies [7–9]. Some scholars conducted research on the elements and functions of the low-carbon policy implementation path, as well as the policy-driven low-carbon transition path, in order to make plans for low-carbon development [10]. Other scholars analyzed the impact of low-carbon policies on the upgrading of industrial structure [11,12], corporate innovation [13–15], energy efficiency [16,17], and carbon emission reduction effect [18,19]. Moreover, several scholars have examined the challenges China faces in pursuing low-carbon development [20,21]. Despite these efforts, research on the overall structure and evolutionary characteristics of low-carbon policy systems has not received sufficient attention. This knowledge gap may affect the accurate assessment of overall policy effectiveness and limit in-depth guidance for future policy optimization. Therefore, it is necessary to conduct an in-depth exploration and analysis of China's low-carbon policy system and its evolutionary characteristics to fully understand its structural features, development patterns, and implementation effects, providing a more robust scientific basis for future low-carbon policy formulation and refinement.

This study attempts to address the following questions: What is the internal logic and system structure of China's low-carbon policies? What are the key themes and core elements embedded in these policies? What are the evolutionary traits that define low-carbon

policies? Answering these questions is essential for several reasons. First, understanding the evolutionary stages provides insights into the historical context, policy priorities, and institutional dynamics shaping China's approach to low-carbon development. This knowledge can inform future policy formulation and implementation strategies, enabling policymakers to build upon past experiences and successes while addressing existing gaps and challenges. Second, identifying key themes and core elements allows for a comprehensive understanding of the objectives, priorities, and strategies embedded within China's low-carbon policies. This understanding is crucial for aligning policy goals with broader national development objectives, promoting coherence across different policy domains, and ensuring the effectiveness and efficiency of policy interventions. Third, examining the system structure of low-carbon policy sheds light on the institutional arrangements, governance mechanisms, and coordination mechanisms involved in policy implementation. This analysis is essential for identifying institutional strengths and weaknesses, improving policy coordination and coherence, enhancing stakeholder engagement and collaboration, and ultimately, achieving the desired outcomes of low-carbon development. Fourth, analyzing the evolutionary traits of low-carbon policies helps to assess the adaptive capacity, resilience, and effectiveness of policy responses to evolving challenges and changing circumstances. By identifying trends, patterns, and lessons learned from past policy experiences, policymakers can better anticipate future challenges, refine policy strategies, and enhance the overall effectiveness and sustainability of China's low-carbon development efforts.

In this study, based on a comprehensive review of China's low-carbon policies, we systematically analyzed their evolutionary trajectory from 2007 to 2022 in terms of time characteristics. The evolution is delineated across three stages: initial exploration, accelerated promotion, and comprehensive implementation. Concurrently, a policy issuing department network for China's low-carbon policies was further constructed, and the latent Dirichlet allocation (LDA) model was used to explore the core themes of China's low-carbon policies. Furthermore, with a focus on the "1 + N" policy system, we utilized a framework that integrates top-level design and core policy elements at various levels to explore the structure of China's low-carbon policy system. Finally, through a comparative analysis of policy focus across the three stages, the evolutionary characteristics of China's low-carbon policies were scrutinized. The overarching aim is to furnish valuable insights for the future formulation and implementation of low-carbon policies.

The rest of this paper is organized as follows: Part 2 covers data and research methods, Part 3 presents research results and discussions, and finally, the conclusions and policy implications are shown in Part 4.

2. Data and Methods

Figure 1 shows the research framework of this paper. First, we collected China's low-carbon policy documents from official Chinese government websites and organized these documents based on policy titles, issuing authorities, publication dates, and policy content. Second, we preprocessed the text data, including word segmentation and keyword extraction. Third, content analysis was used to examine the external features of China's low-carbon policies, encompassing temporal characteristics, issuing entities, and thematic features. Fourth, we conducted an in-depth exploration of the "1 + N" policy system. This phase entailed a meticulous analysis of the structure of China's low-carbon policy system through the construction of a framework that integrates top-level design and the analysis of core policy elements at various levels. Finally, the policy evolution process was investigated by analyzing the policy focus of different stages.

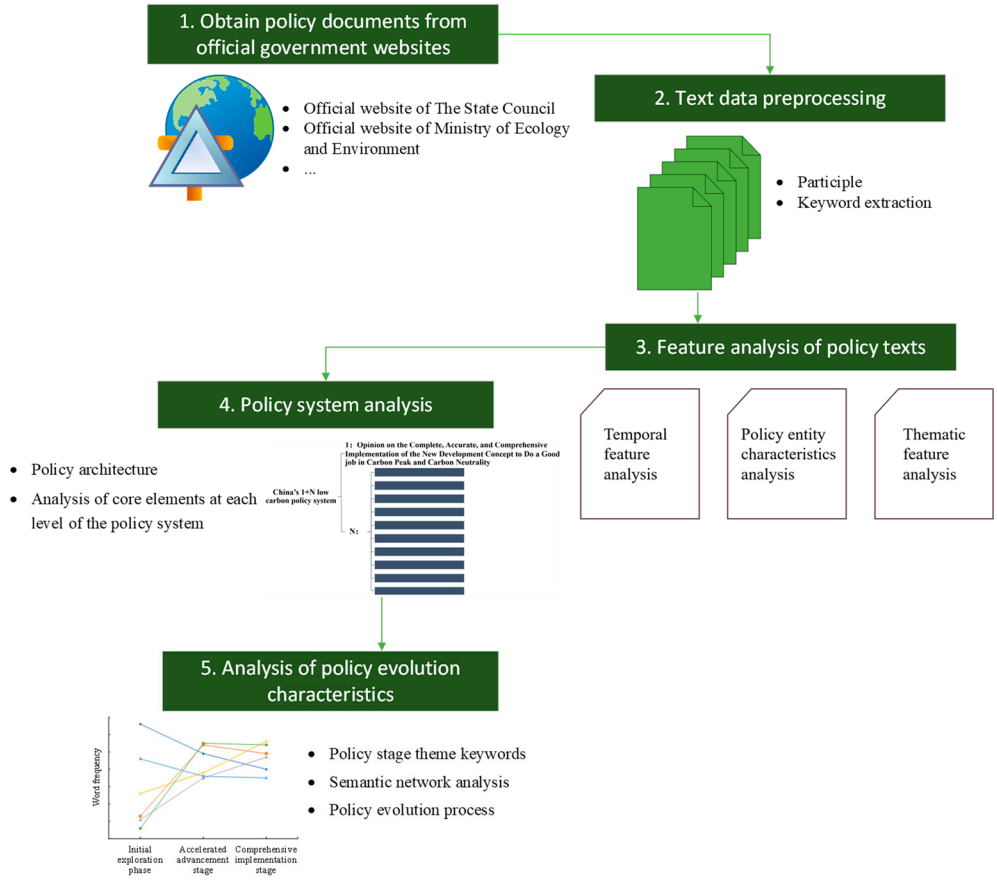

Figure 1. Research framework.

2.1. Data Sources

The subject of this study encompasses low-carbon-related policies enacted in China from 2007 to 2022, including relevant policies, regulatory laws, institutional frameworks, and measures. To ensure the validity and accuracy of the data, policies were collected from official government websites such as the State Council, the Ministry of Ecology and Environment, the National Development and Reform Commission, the Ministry of Transport, the Ministry of Industry and Information Technology, the Ministry of Housing and Urban–Rural Development, the Ministry of Science and Technology, and other government agencies. The policy collection adhered to the following three principles: ① Issuing entities were the State Council, the central departments, and their directly affiliated institutions and local governments. ② Policy types included plans, opinions, notices, laws, and regulations, among other normative documents. ③ Policies were directly related to content such as "carbon peak", "carbon neutrality", "carbon market", "low carbon", and "carbon reduction". Subsequently, the collected policy texts were screened to exclude meeting notices, duplicate policies, etc. In the end, 206 policy samples were gathered, comprising 85 central and 121 local policies. The retrieved policy text data was stored in an Excel spreadsheet, with each data entry containing the serial number, policy name, issuing entity, document number, issuance date, data source, and policy content.

Figure 2 shows the distribution of entities responsible for issuing low-carbon policies in China. Among the 20 entities involved, those issuing a relatively large number of low-carbon policies include the National Development and Reform Commission, the Ministry of Industry and Information Technology, and the Ministry of Transport.

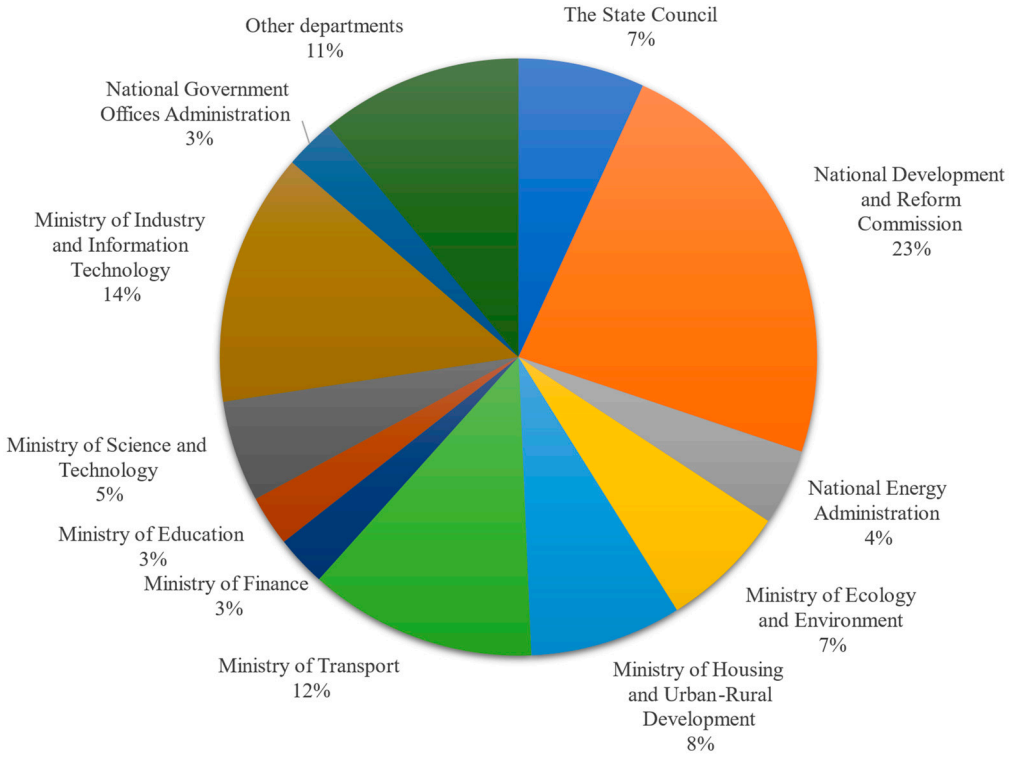

Figure 2. Distribution of issuing entities of low-carbon policies. The other departments category comprises the Ministry of Agriculture, the Ministry of Commerce, the Ministry of Natural Resources, the Ministry of Water Resources, the Forestry Bureau, the Meteorological Bureau, the Oceanic Bureau, the People's Bank of China, and the National Railway Administration.

According to the Green Finance Committee of the China Society for Finance and Banking [22], the total investment demand in the green low-carbon sector in China from 2021 to 2050 is estimated to reach RMB 487 trillion. This implies that over the next 30 years, China will need to invest more than RMB 16 trillion annually in this sector. Of this, fiscal funds are expected to contribute approximately RMB 1 trillion per year, and these funds will also be responsible for leveraging private investments in renewable energy development, energy efficiency improvements, clean transportation, green buildings, and low-carbon manufacturing. As reported by the Ministry of Finance, China's total expenditure on ecological and environmental protection in 2021 amounted to RMB 821 billion, accounting for nearly 3% of the general public budget expenditure. The Budget Law mandates the establishment of green government funds dedicated to green development. In this context, the Ministry of Finance, the Ministry of Ecology and Environment, and the Shanghai Municipal Government jointly initiated the National Green Development Fund in 2020. This is the first national-level government investment fund in the green sector, with an initial total fund size of RMB 88.5 billion, including a central government contribution of RMB 10 billion. The fund primarily targets highly public, high-risk, low-return, and financing-challenged environmental projects. Additionally, in the 2023 budget, Beijing allocated RMB 17.64 billion to energy conservation and environmental protection, significantly promoting the Green Beijing Strategy. This initiative supports green development and the carbon peaking and carbon neutrality goals, further improving environmental quality. This includes key support for green and low-carbon circular development, advancing low-carbon technology research, implementing low-carbon pilot projects, and conducting green retrofits in municipal industrial parks to reduce energy consumption and pollution. Moreover, Beijing has increased support for green development in agriculture, forestry, water, transportation, disaster prevention, and emergency management, maximizing the fiscal support for green initiatives.

These data illustrate the significant investment and fiscal support from the Chinese government in the green low-carbon sector. Through the formulation and implementation of policies, the government actively promotes low-carbon development and the achievement of carbon neutrality goals.

2.2. Methods

2.2.1. Participle

Pre-processing of policy text data is needed to improve the accuracy and efficiency of analysis. A word segmentation tool was used to break down the policy text into words. We used Jieba, a Python Chinese word segmentation component that provides a dictionary of Chinese character prefixes. For words present in the prefix dictionary, a directed acyclic graph (DAG) is constructed, and word segmentation can be accomplished through dynamic programming. For words that do not exist in the prefix dictionary, a hidden Markov model is required. In addition, developers can also specify their own custom dictionaries to include words that are not in the Jieba thesaurus, and add new words to ensure a higher accuracy rate. Special words involved in low-carbon policies such as "green development", "energy conservation", "emission reduction", "carbon trading", "carbon peak", and "carbon neutrality" were added to the custom dictionary to improve the accuracy of word segmentation. Then, the Harbin Institute of Technology deactivation vocabulary was used to clean the word segmentation results.

2.2.2. Keyword Extraction

Keyword extraction is a technology or process for extracting key and important terms from unstructured text documents [23], and the TF-IDF algorithm was used to extract keywords from low-carbon policies in this study. TF-IDF is a statistical method used to assess the importance of a word or phrase in a corpus.

The formula for calculating word frequency is as follows:

$$tf_{ij} = \frac{n_{i,j}}{\sum n_j} \tag{1}$$

where $n_{i,j}$ represents the number of occurrences of the word i in file j, and $\sum n_j j$ represents the sum of the number of times all words appear in file j.

Inverse document frequency (IDF) is a measure used to evaluate the importance of a word within a corpus. The fundamental idea is that if a word appears in many documents, it has a lower ability to distinguish between documents; conversely, if a word appears in only a few documents, it has a higher distinguishing power. The IDF value increases proportionally to the rarity of the word in the corpus. The formula for calculating the reverse file frequency is as follows:

$$idf_i = log\frac{|D|}{|df(i)+1|} \tag{2}$$

where $|D|$ is the total number of files in the corpus, $df(i)$ indicates the number of files that contain word i.

A high frequency of words within a particular file, as well as a low file frequency of that word in the overall set of files, can result in a high-weight TF-IDF. Therefore, TF-IDF tends to filter out common words and keep important ones. TF-IDF is expressed as:

$$TF - IDF = \frac{n_{i,j}}{\sum n_j} \times log\frac{|D|}{|df(i)+1|} \tag{3}$$

2.2.3. Semantic Network Analysis

Semantic networks use entities and their semantic relationships to express knowledge, and are used to reveal associations and interactions between words in textual data [24].

In this study, semantic network analysis was used to reveal the connections between the core concepts in low-carbon policy, and the keyword connections between different policy stages were analyzed to elucidate the horizontal correlation between policies, to better understand the construction and evolution process of the policy system.

2.2.4. Topic Modeling

Latent Dirichlet allocation (LDA) is a text analysis method used to discover potential topic structures in text data [25]. In the LDA model, each document defines a probability distribution for a topic, and each topic defines a probability distribution for a word. The LDA assumes that when a document d is generated, a topic Z_{dn} is extracted from the document, then a word W_{dn} is extracted from the topic. The process of producing each word is independent of each other, generating one word at a time. The distribution of topics θ_d obeys the Dirichlet distribution, in which each theme is independent of the others.

$$p(\theta, z, w|\alpha, \beta) \tag{4}$$

where α and β are Dirichlet priors and model hyperparameters. In order to infer the hidden topic structure, the joint distribution needs to be used to calculate the conditional distribution of the topic structure of the document, which is calculated as follows:

$$p(\theta, z|w, \alpha, \beta) = \frac{p(\theta, z, w|\alpha, \beta)}{p(w|\alpha, \beta)} \tag{5}$$

The denominator of this equation is the marginal probability of the observation, which can be calculated by summing the joint distributions of each possible hidden topic structure. In this paper, the Python Gensim library was used to implement LDA topic modeling.

The LDA topic model cannot determine the optimal number of topics. The consistency indicators were used to determine the optimal number of topics in this study, and the basic idea is to evaluate the correlation between words in the generated topics. Specifically, the words with the largest weight in each topic can be selected and we can calculate the similarity between these words, where mutual information is generally considered a valid similarity measure. Finally, an aggregate function can be used to consolidate all paired scores. The formula for calculating pointwise mutual information (PMI) between pairs of words (w_i, w_j) is as follows

$$PMI(w_i, w_j) = \frac{logp(w_i, w_j)}{p(w_i)p(w_j)} \tag{6}$$

In this study, LDA modeling was employed to extract and analyze the core themes of China's low-carbon policies, providing insights into the evolution and focus of these policies over time.

3. Results and Discussion

3.1. Analysis of Policy Characteristics

3.1.1. Temporal Feature Analysis

Figure 3 shows the temporal evolution of the number of low-carbon policy announcements in China. Results indicate that from 2007 to 2015, China's low-carbon policies increased at a relatively modest pace, averaging five policies issued annually. The year 2016 marked a crucial turning point when China issued 20 relevant policies, coinciding with the signing of the Paris Agreement by 171 countries. This event signaled the beginning of a shift towards a net-zero emissions world. However, during the accelerated promotion stage (2016–2019), the number of policies issued fluctuated and even declined, with only five policies issued in 2019. This decrease can be attributed to several factors. Firstly, the initial burst of policy activity in 2016 likely reflected the immediate response to international commitments and the need to quickly establish foundational policies and frameworks. As

these initial frameworks were set, the focus may have shifted towards implementing and refining existing policies rather than issuing new ones. Secondly, the decrease could also reflect a period of policy evaluation and adjustment, where the government assessed the effectiveness of earlier policies and made necessary modifications before issuing new directives. Another significant milestone was reached in 2021, with the issuance of 43 relevant policies. On 22 September 2020, China officially announced its carbon peak and carbon neutrality goals at the 75th session of the United Nations General Assembly. Driven by the commitment to peak carbon and achieve carbon neutrality, the year 2022 witnessed the highest number of low-carbon policies issued in China, totaling 48. Consequently, the evolution of China's low-carbon policies from 2007 to 2022 is divided into three stages: the initial exploration stage (2007–2015), the accelerated promotion stage (2016–2019), and the comprehensive implementation stage (2020–2022).

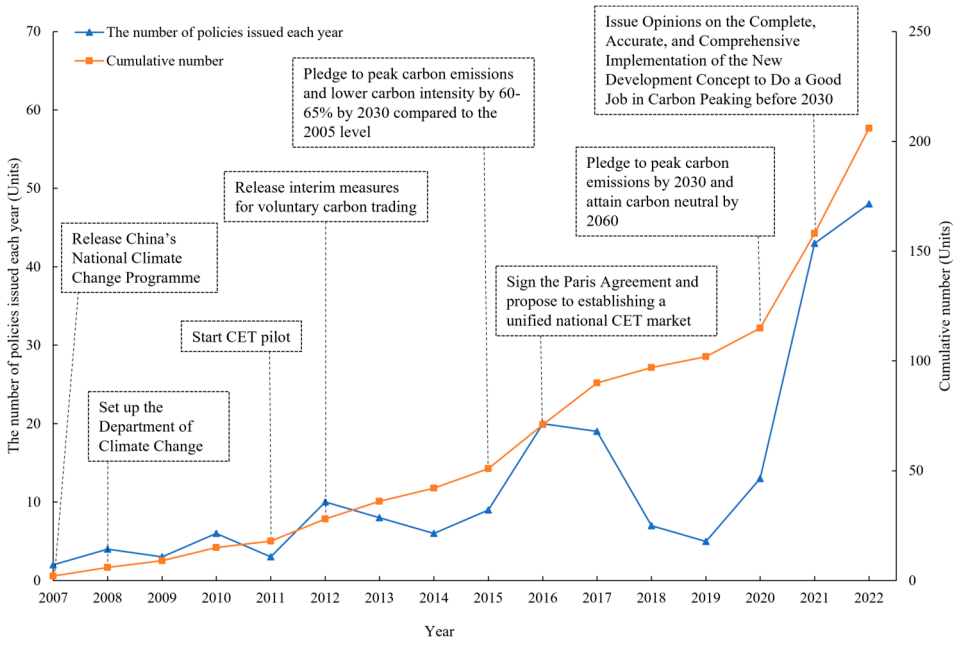

Figure 3. Number of China's low-carbon policy issuances and key events.

During the initial exploration stage (2007–2015), due to the lack of comprehensive policies and specific targets, China's CO_2 emissions experienced a significant surge. Following its accession to the World Trade Organization, China's expanding production capacity resulted in substantial emission increases, with an annual average growth rate of 13% during the period from 2002 to 2007 [26]. As China surpassed the United States to become the world's largest emitter, it came under heightened international scrutiny. In response, the Chinese government promulgated the National Climate Change Programme in 2007. This program encompasses the ideology, principles, objectives, policies, and measures of climate governance, marking the first comprehensive climate policy for both China and developing countries [27]. China's approach to climate change aligns with the principles of authoritarian environmentalism, which is centered on administrative power. The Department of Climate Change (DCC), established in 2008 as China's chief climate agency, is responsible for drafting climate strategies and policies, participating in international negotiations, and fulfilling obligations under the UNFCCC [28]. In 2015, China pledged to peak emissions and reduce carbon intensity by 60–65% from the 2005 levels by 2030 [29]. In pursuit of these objectives, various government agencies began formulating climate-related policies. Between 2007 and 2015, climate change emerged as a significant concern for China, resulting in comprehensive and substantial climate policies. China's climate achievements during this period were notable, including a reduction in energy intensity by 18.2% and carbon intensity by 20% [30].

Subsequently, entering the accelerated advancement stage (2016–2019), China signed the Paris Agreement and formally initiated the carbon emission trading (CET) system, incorporating climate change into national strategy. The post-Paris era presents new challenges and opportunities for China, as both international and domestic expectations shape its leadership role in global climate governance, particularly after the U.S. withdrew from the Paris Agreement and China adopted long-term sustainable development philosophies [31]. Despite the issuance of numerous policies, China's carbon emissions continued to rise due to its energy-intensive and heavy industry-based growth model. Between 2007 and 2016, China's emissions surpassed the combined totals of the U.S., India, and Russia. As a result, China is now focused on transitioning towards a more sustainable and inclusive development model [32]. In 2016, China submitted its First Nationally Determined Contribution (NDC) as a supplement to its commitments under the Paris Agreement, underscoring its dedication to climate action and sustainable development [32].

In the comprehensive implementation stage (2020–2022), China has proposed carbon-peak and carbon-neutral goals, and has released corresponding implementation plans for energy conservation, emission reduction, and technological support for achieving carbon peak and carbon neutrality, guiding the nationwide scientific and technological community, industries, regions, and enterprises. From a domestic perspective, climate governance aligns closely with China's national strategy for economic restructuring, aiming to optimize the industrial structure and energy mix. Consequently, China's climate objectives have been integrated into the 13th and 14th Five-Year Plans. Presently, China is committed to developing the "1 + N" climate policy system, wherein "1" represents the guiding ideology and top-level design, while "N" refers to the action plans for key sectors. This approach underscores China's dedication to a comprehensive and coordinated framework for achieving its climate goals [32].

3.1.2. Analysis of Cooperation of Policy Subjects

From the data on joint publications (Figure 4), the National Development and Reform Commission, the National Energy Administration, the Ministry of Ecology and Environment, the Ministry of Housing and Urban–Rural Development, the Ministry of Transport, and the Ministry of Finance play significant roles in formulating and promoting China's low-carbon policies, demonstrating a high level of collaboration. Among them, the National Development and Reform Commission, as one of the leading departments, holds a leadership position in the formulation of China's low-carbon policies (20%). It exhibits a high frequency of collaboration with other departments such as the Ministry of Ecology and Environment (16%) and the Ministry of Transport (12%), highlighting the coordination of policy formulation.

This interdepartmental collaboration is essential for addressing the multifaceted challenges of low-carbon development [33], which encompass a wide range of sectors, including energy production, transportation, urban development, and financial investment. For instance, the integration of the Ministry of Transport in policy-making reflects the critical role of reducing emissions from the transportation sector, which is a major contributor to national greenhouse gas emissions [34]. Similarly, the involvement of the Ministry of Housing and Urban–Rural Development underscores the importance of promoting sustainable urban planning and green building standards [35]. The Ministry of Finance's role in funding and incentivizing green projects has been pivotal in mobilizing financial resources for low-carbon initiatives [36]. The high frequency of collaboration among these ministries indicates an ongoing effort to align their respective policies and actions with China's broader climate goals. This alignment is crucial for ensuring policy coherence and avoiding conflicts or redundancies in policy implementation, thereby enhancing the overall effectiveness of China's low-carbon strategy [37].

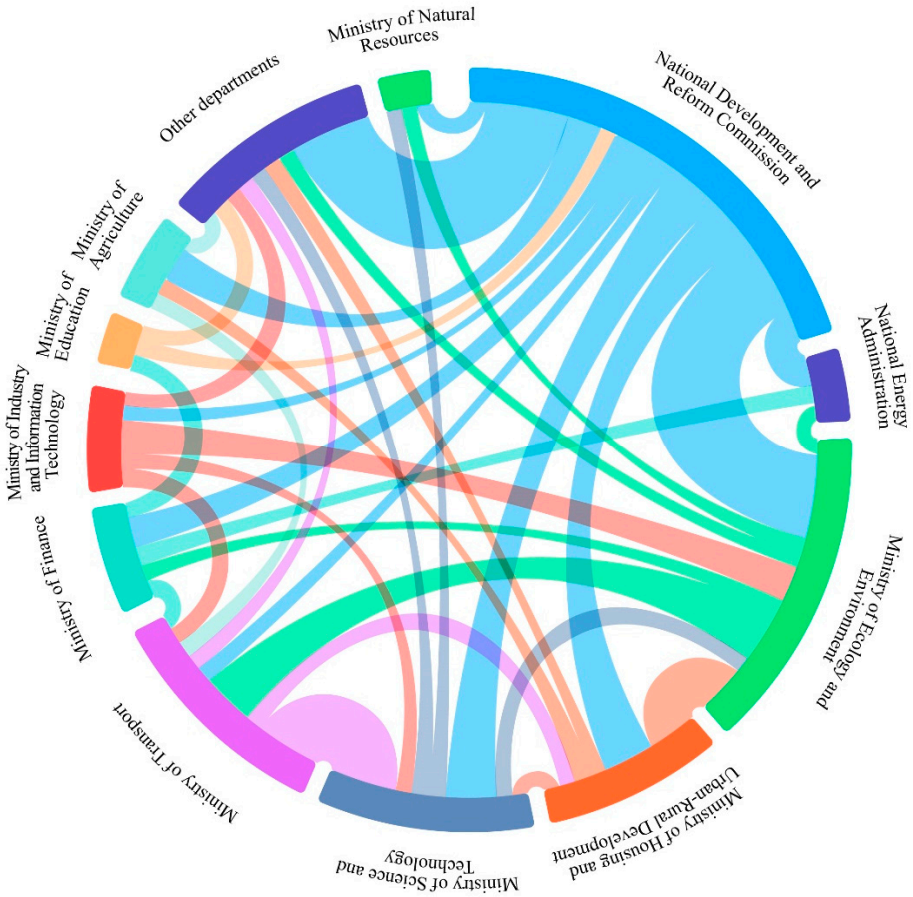

Figure 4. Collaborative issuers of low-carbon policies.

3.1.3. Thematic Feature Analysis

The LDA model was used for topic analysis of low-carbon policy texts. First, the consistency indicator was used to agree that the optimal number of topics is eight. Second, with the optimal number of topics applied to the LDA model, the top 15 keywords with the highest weights were extracted for each topic, and each topic was named (Figure 5).

Based on the analysis results, eight key themes were identified, involving carbon emission trading market and regulatory mechanism, energy conservation and emission reduction, circular economy and sustainable development, greenhouse gas monitoring and emission management, industrial low-carbon transformation, low-carbon technological innovation, sustainable urban planning and construction, and publicity, education, and social participation. Specifically, the theme of "Carbon emission trading market and regulatory mechanism" underscores China's notable initiative in introducing market mechanisms to address climate change. The Chinese government has taken substantial steps in establishing carbon emission trading market and implementing associated policies. This strategic measure is a response to the heightened awareness of environmental issues and the evolving international climate agenda. The theme of "Energy conservation and emission reduction" reveals China's positive measures to promote energy conservation and emission reduction in the fields of industry, transportation, and agriculture. The government's policies promoting the use of clean energy and improving energy efficiency may be driven by the pursuit of sustainable development. The theme of "Circular economy and sustainable development" signifies positive strides in China's economic sustainable development. This progress may be attributed to government initiatives promoting resource recycling and the development of environmentally friendly industries. "Greenhouse gas monitoring and emission management" emphasizes China's comprehensive approach to monitoring and managing greenhouse gas emissions. Strengthened regulation of enterprises and industrial

sectors aims to enhance carbon emission management and reduce overall greenhouse gas emissions. The theme of "Industrial low-carbon transformation" reflects China's efforts in transforming industrial structures. The government encourages enterprises to innovate technologically, undergo transformation, and upgrade processes to reduce energy consumption and carbon emissions, thereby promoting low-carbon development in industries. "Low-carbon technological innovation" highlights China's significant initiatives in technological innovation. Government support for research and application of low-carbon technologies aims to facilitate their widespread adoption in energy, construction, and transportation sectors, contributing to achieving carbon reduction goals. "Sustainable urban planning and construction" demonstrates China's key initiatives in urban planning and construction. Government encouragement for sustainable development measures, including green building and intelligent transportation, seeks to enhance urban environmental quality and residents' quality of life. "Publicity, education and social participation" underscores the Chinese government's active promotion of awareness through publicity, education, and social participation. Through these initiatives, the government aims to increase public awareness and consciousness of low-carbon living, fostering collective participation in low-carbon initiatives across society.

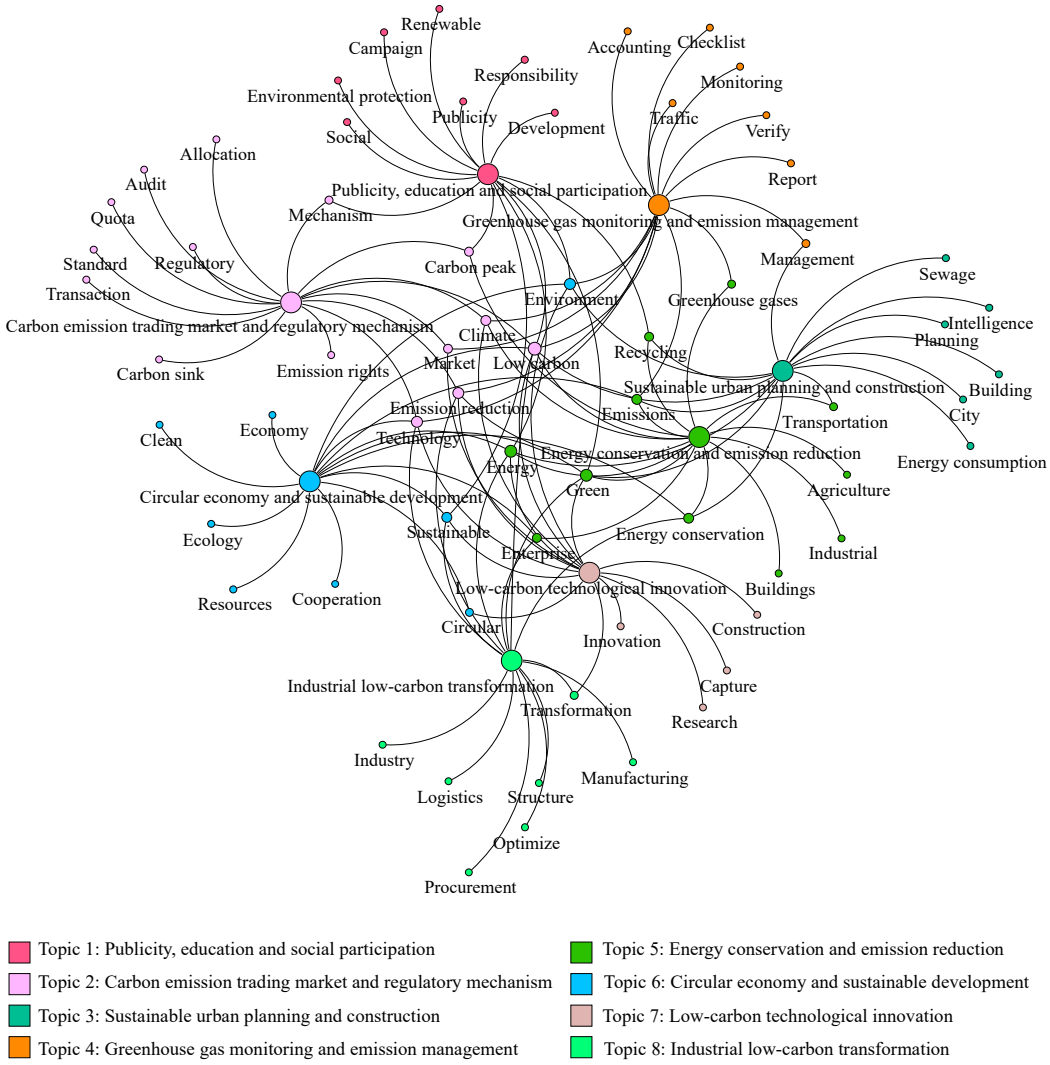

Figure 5. Keywords of each topic.

3.2. Policy System Analysis

3.2.1. Policy Architecture

With the introduction of the carbon peak and carbon neutrality goals ("dual carbon" goal), China's low-carbon policies have evolved to form a "1 + N" policy framework centered around "carbon peak" and "carbon neutrality" (Figure 6). The "1" signifies the top-level design of the "dual carbon" goals, explicitly outlining primary objectives, decarbonization paths, and corresponding measures to achieve carbon peak and carbon neutrality. The "N" encompasses policy measures and actions across various sectors and industries. This study thoroughly analyzes the policy framework structure of China's low-carbon policies, with a focus on the top-level strategy, uncovering the core elements of different levels of low-carbon policies, and understanding the interconnections between high-level and low-level policies. The goal is to provide strategic recommendations for further advancing China's low-carbon development and achieving the "dual carbon" goal.

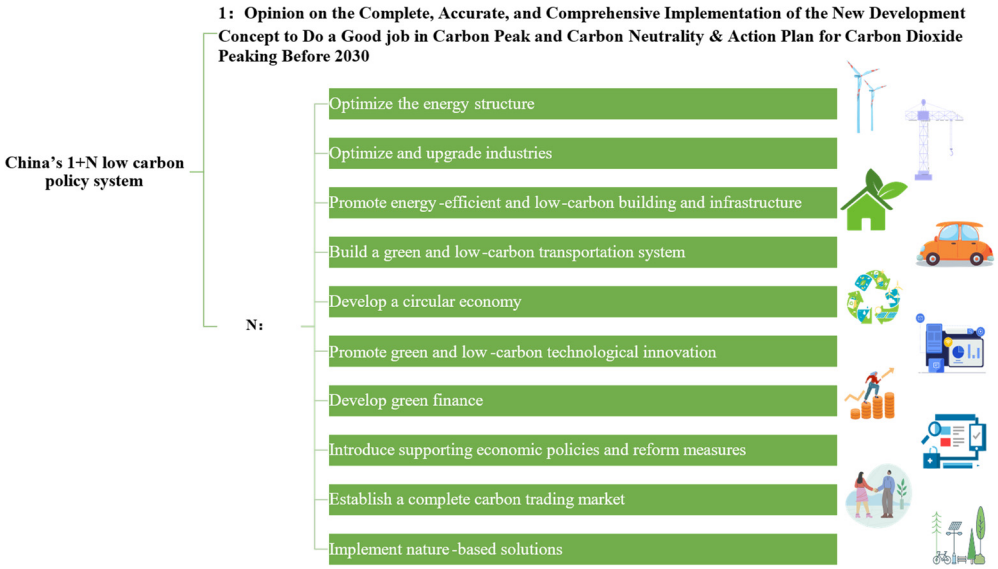

Figure 6. China's "1 + N" double carbon policy system.

3.2.2. Analysis of Core Elements at Each Level of the Policy System

Based on the "1 + N" low-carbon policy framework constructed in Figure 6, the top 15 core keywords with the highest weights were extracted from policies at each level to investigate the core elements of policies at various levels (Figure 7). The weights of the keywords were determined by their frequency of occurrence and their relevance within the policy texts, indicating the importance and focus of different policy elements. Specifically, higher weights represent keywords that are more frequently mentioned and more central to the policy's objectives and implementation strategies.

Figure 7 indicates that the top-level design focuses on the overall architecture of the policy, with an emphasis on carbon emission reduction, green development, and carbon neutrality. This reflects policymakers' recognition of climate change's global challenges and commitment to steering China toward a more sustainable future. The "N" component encompasses diverse areas, including optimizing energy structure, upgrading industries, promoting energy-efficient buildings, fostering green transportation, advocating for a circular economy, encouraging technological innovation, supporting green finance, and implementing economic policies aligning with environmental goals [38]. Key terms associated with these policy measures include energy, green, urban, transportation, technology, and environmental protection. These policies work cohesively to support overarching carbon reduction objectives while addressing specific challenges within each sector, ensuring consistency within the overall framework. The characteristics of this policy system are prominently reflected in its multidimensional coverage, encompassing various aspects such

as green initiatives, low-carbon strategies, carbon peak, and carbon neutrality, reflecting the comprehensive considerations of the Chinese government in tackling climate change and fostering sustainable development [39]. The system spans diverse industries, including energy, industry, construction, transportation, and finance, highlighting its comprehensive coverage and the active participation of various sectors in policy implementation. The emphasis on technological innovation, clean energy, and socio-economic reforms underscores the determination and actions of the Chinese government in promoting advancements in technology, environmental protection, and socio-economic sustainability, such as the development of high-performance biochar adsorbents for mercury removal, which play a crucial role in achieving sustainable development goals [40]. Simultaneously, the emphasis on keywords such as environmental protection, resource recycling, and ecological environmental protection underscores the environmental and sustainable development orientation of the policy system construction.

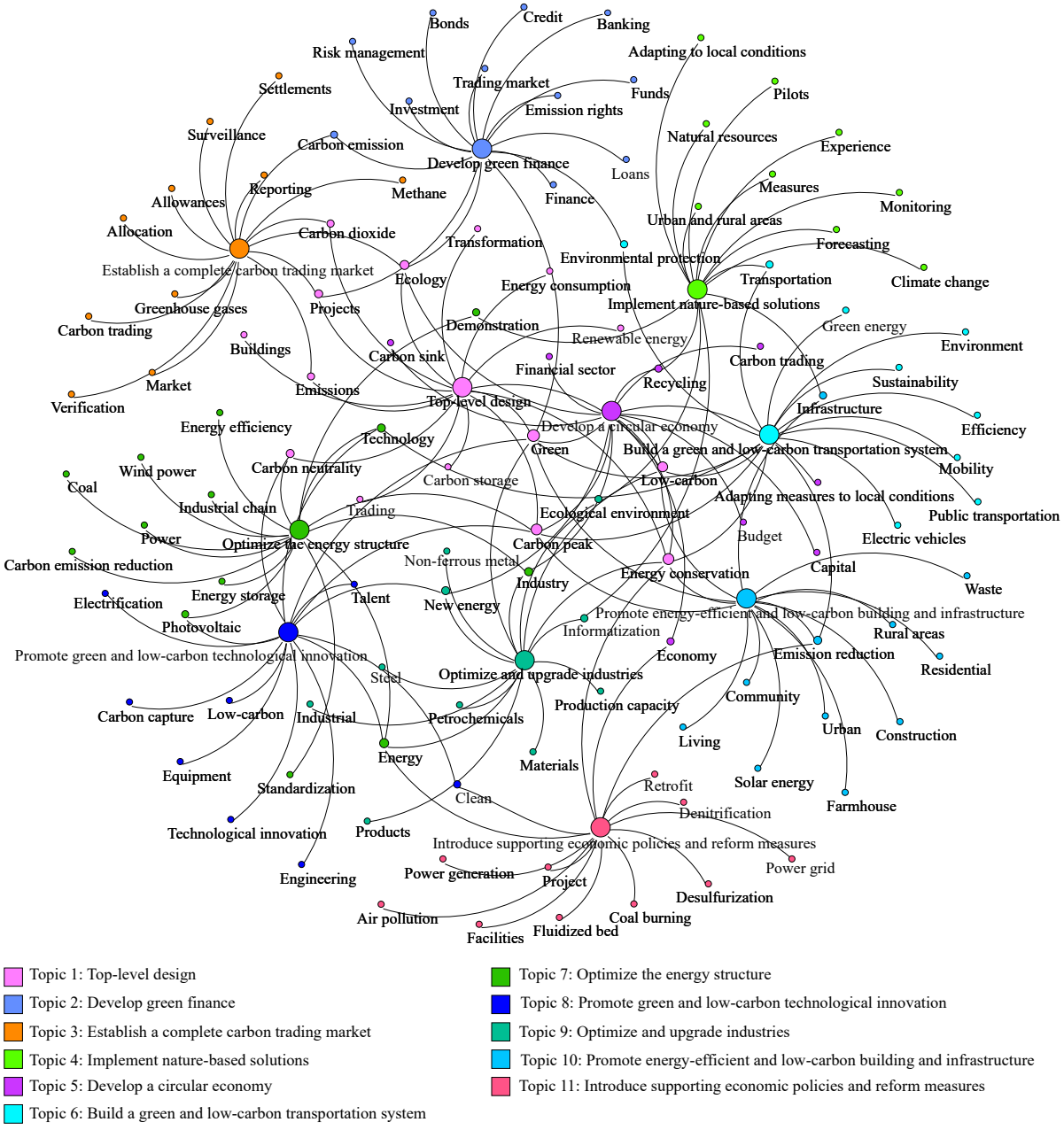

Figure 7. Keywords of dual carbon policies at all levels.

Furthermore, the analysis reveals a close correlation and mutual support between the themes covered by low-carbon policies and the framework of the "1 + N" policy system. These connections signify the comprehensiveness and systematic nature of China's low-carbon policies, illustrating policymakers' comprehensive deployment of measures to drive carbon reduction, economic transformation and upgrading, and ecological environmental protection. This holistic policy will help China address climate change challenges and lay a solid foundation for achieving important goals such as carbon peak and carbon neutrality [41,42].

3.3. Policy Evolution Characteristics Analysis

3.3.1. Theme Keywords of Policy Stage

To grasp the core elements of low-carbon policies more accurately in each stage, the TF-IDF algorithm was used to extract the 15 core keywords with relatively higher weights from low-carbon policies in each stage (Table 1).

Table 1. Keywords and word frequency in three stages of policy.

Initial Exploration Stage		Accelerated Advancement Stage		Comprehensive Implementation Stage	
Keywords	**Frequency**	**Keywords**	**Frequency**	**Keywords**	**Frequency**
Energy conservation	0.076	Green development	0.065	Carbon market	0.066
Low carbon	0.063	Transportation	0.064	Green development	0.064
Carbon reduction	0.056	Low carbon	0.060	Transportation	0.059
Environmental protection	0.049	Energy conservation	0.059	Technology	0.057
Energy	0.041	Energy	0.054	Carbon peak	0.054
Transformation	0.040	Greenhouse gas	0.051	Low carbon	0.053
Greenhouse gas	0.039	Economy	0.050	Carbon neutrality	0.051
Carbon market	0.036	Carbon market	0.048	Energy conservation	0.050
Ecology	0.032	Carbon reduction	0.046	Energy	0.048
Transportation	0.023	Technology	0.045	Carbon reduction	0.045
Technology	0.021	Enterprise	0.037	Economy	0.041
Informatization	0.019	Ecology	0.030	Environment	0.036
Green development	0.016	Circulate	0.021	Ecology	0.031
Enterprise	0.012	Environment	0.016	Transformation	0.022
Climate	0.009	Sustainable	0.011	Emission rights	0.016

In the initial exploration stage, policymakers primarily focused on energy conservation, emissions reduction, and environmental protection. High-frequency topic words such as "energy conservation", "low carbon", "carbon reduction", "carbon market", and "green development" underlined a commitment to reducing greenhouse gas emissions and promoting the combined green and sustainable development of the economy and the environment. During the accelerated advancement stage, policy priorities became more systematic and profound, emphasizing green transformation, sustainable development, the promotion of carbon market construction, and circular economy. This indicates that the policy focus has begun to shift towards the synergistic development of economic restructuring and green development, reflecting a more comprehensive and strategic approach. In the comprehensive implementation stage, policies further strengthened carbon emissions management and regulation, utilizing carbon market mechanisms to guide enterprises in emissions reduction and facilitate carbon trading. There was also a heightened emphasis on technological innovation and its application to promote the development and implementation of green technologies. Additionally, policies aimed to balance economic development with ecological environmental protection, reflecting China's ambitious commitment to achieving carbon peak and neutrality goals.

The implementation of these phased policies holds significant importance for China's carbon reduction targets, potentially accelerating progress in the field of carbon emissions reduction. The evolution of policy priorities across stages demonstrates a strategic and adaptive approach by the Chinese government, emphasizing the integration of eco-

nomic development with environmental sustainability in the pursuit of ambitious carbon reduction goals.

3.3.2. Semantic Network Analysis

Semantic network analysis focuses on examining the interrelationships between keywords, providing insights into the lateral correlations between policies at different stages. A semantic network is constructed by analyzing the semantic connections between keywords, serving as a basis for understanding these correlations.

The semantic network for the initial exploration stage (Figure 8) illustrates that "energy conservation" and "development" are central nodes connected to the majority of keywords, including "energy", "environmental protection", "transport" and "enterprises". This connectivity suggests that, despite the issuance of various types of low-carbon policies during this stage, they all orbit around the core elements of energy conservation, emissions reduction, and low-carbon development. These policies exhibit complementarity and cooperation, working collectively to drive the realization of China's transformation goals.

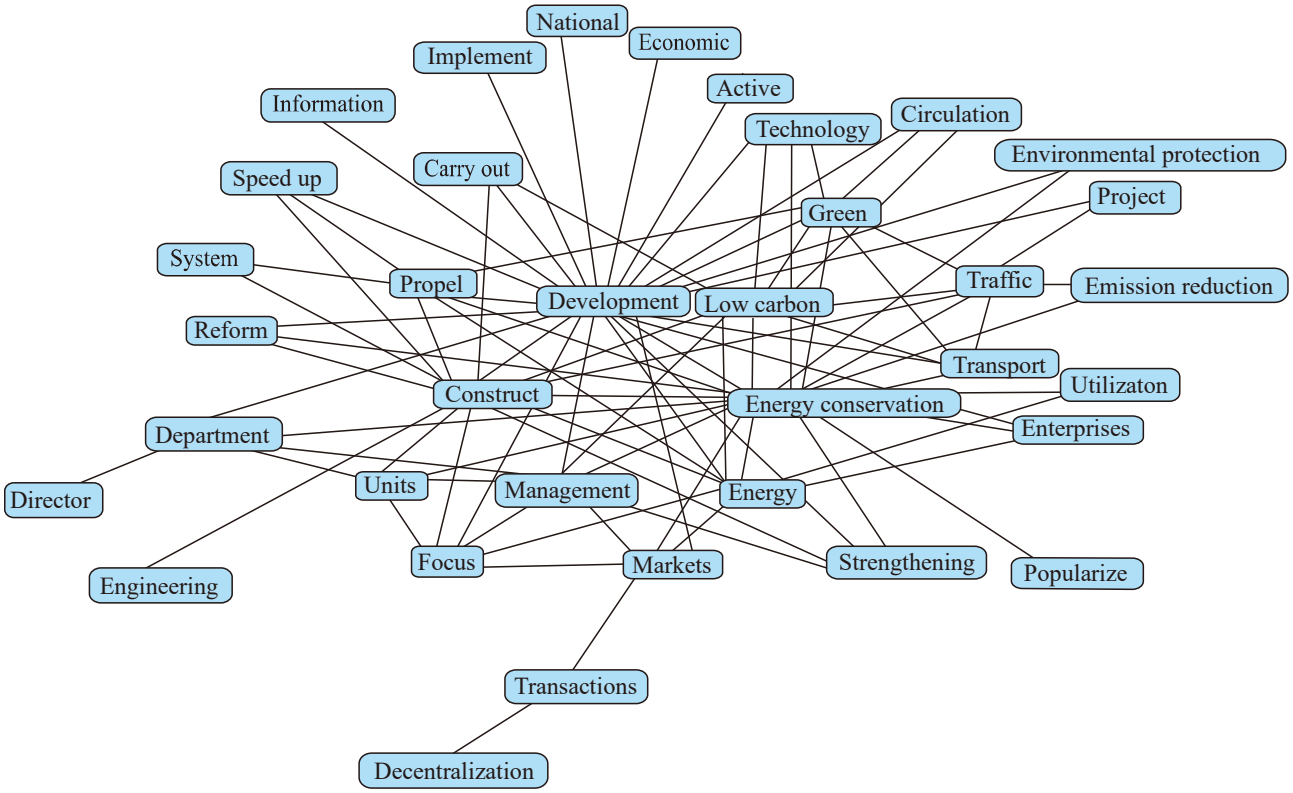

Figure 8. The semantic network of initial exploration stage.

In the semantic network for the accelerated advancement stage (Figure 9), "transformation", "green", "development" and "economy" as the keywords, highlighting the central role of green development policies in the policy framework. Green development policies emphasize the coordinated development of the economy, environment, and society, with a focus on sustainable development practices. The increased complexity of the network structure indicates a growing interconnectedness between policies, fostering a situation where developments in various sectors synergistically advance. Words such as "markets", "management", and "clean" at the periphery of the semantic network suggest that policy implementation requires more refined oversight and supervision, with a concurrent focus on the construction of the carbon market.

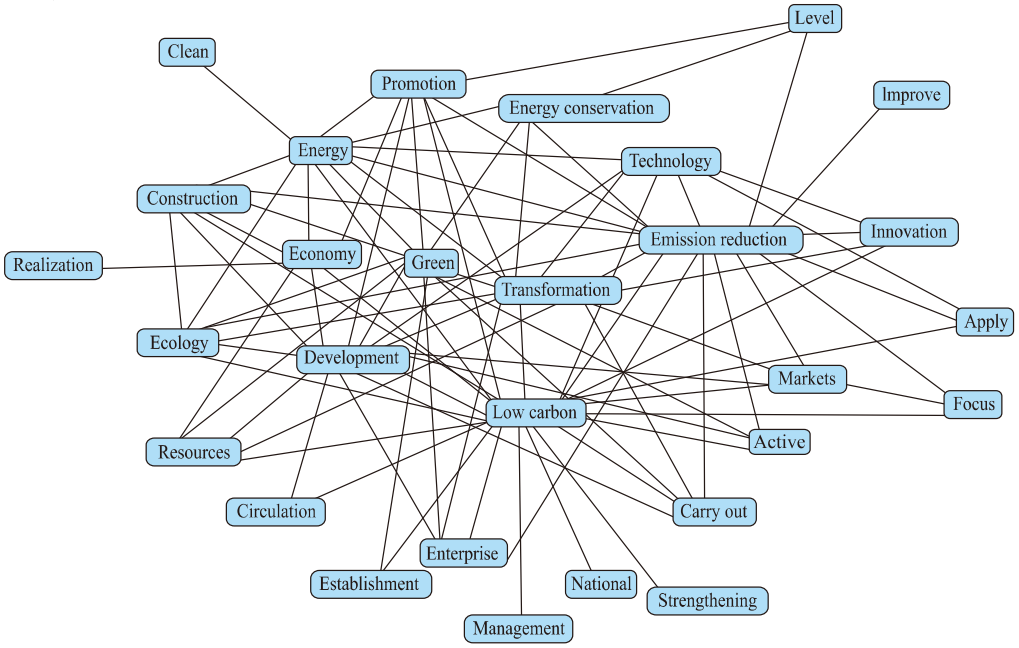

Figure 9. The semantic network of accelerated advancement stage.

In the semantic network for the comprehensive implementation stage (Figure 10), "carbon peak", "carbon neutrality", "green", "trading", and "technology" as the core keywords, underscoring the significance of advancing green technological innovation and establishing a robust carbon market mechanism. At the network's periphery, words such as "ecology", "system", and "energy conservation" indicate the need to consider ecological protection, energy system development, and energy conservation while advancing the "dual carbon" goals. This emphasizes the necessity for collaborative efforts and strengthened international cooperation to collectively address the challenges posed by global climate change.

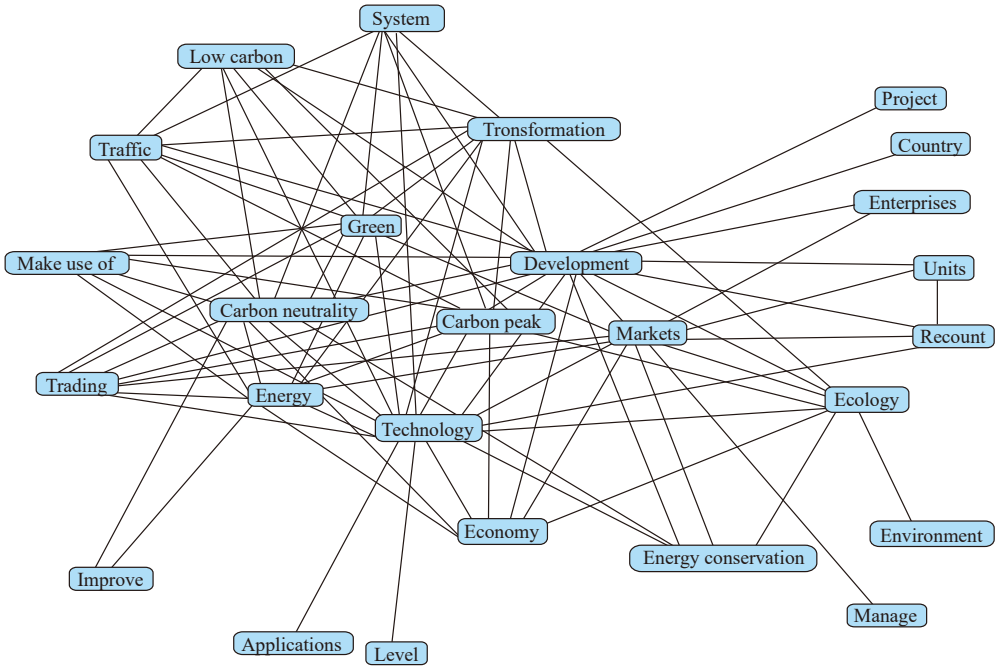

Figure 10. The semantic network of comprehensive implementation stage.

3.3.3. Policy Evolution Process

Expanding on the analysis of horizontal interconnections among different stages of low-carbon policies, this paper further explores the evolution characteristics of low-carbon policies by analyzing the vertical variation of keyword frequency in different stages. Figure 11 illustrates the relative word frequency changes of some keywords in China's low-carbon policies across different stages.

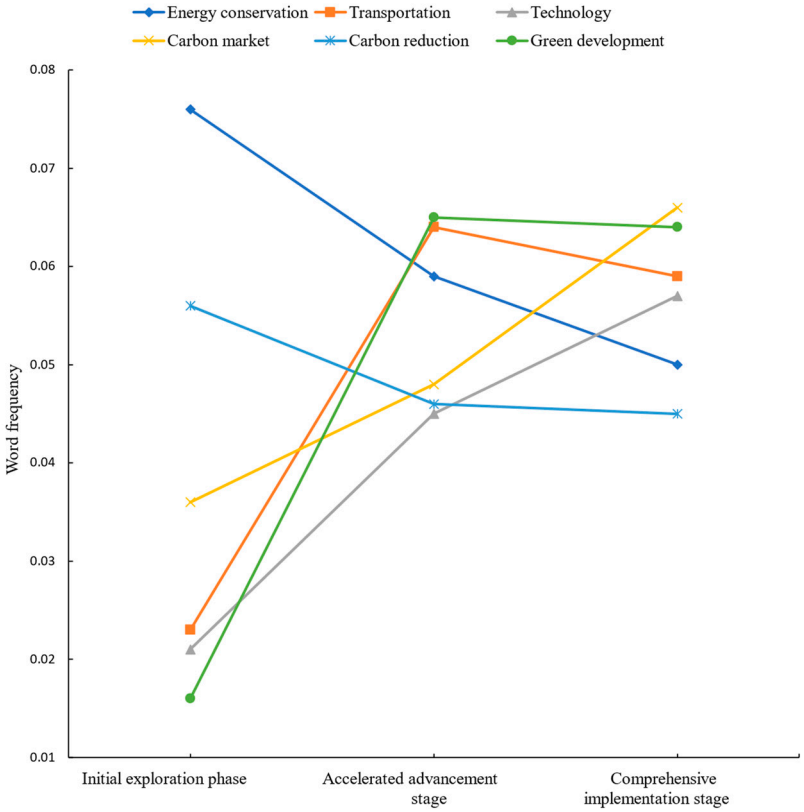

Figure 11. The word frequency change of core keywords from 2007 to 2022.

The result shows that during the initial exploration stage, the focus is on energy conservation, emission reduction, and environmental protection. The accelerated advancement stage shifts the emphasis to industrial upgrading and adjustments in the energy structure. In contrast, the comprehensive implementation stage prioritizes the construction of the carbon market and innovative development. These shifts in focus reflect the adaptability and flexibility of the Chinese government in addressing climate change and promoting sustainable development over time. The evolving emphasis on different aspects illustrates a dynamic response to changing environmental and developmental needs, showcasing the government's strategic approach in aligning low-carbon policies with the evolving landscape of challenges and opportunities.

In summary, the trajectory of China's low-carbon policies reveals a gradual shift in policy focus. Initially, there was a singular emphasis on carbon emission restrictions, which has evolved into a more coordinated approach encompassing the development of the economy and society. This transition further extended to emphasize industrial transformation and upgrading, and ultimately to prioritize the development of carbon markets and technological innovation. This evolutionary process underscores the evolving understanding of environmental and economic issues by the Chinese government, reflecting an increasing emphasis on sustainable development and the cultivation of a low-carbon economy.

Regarding policy implementation, China has progressively established a comprehensive legal and regulatory framework, along with a robust management system. These

measures are designed to enhance the feasibility and effectiveness of policies. In essence, the evolution of China's low-carbon policies signifies continuous adjustments and improvements, underscoring the nation's relentless efforts and achievements in addressing climate change and advancing sustainable development. This adaptive approach highlights China's commitment to staying responsive to the dynamic challenges posed by environmental concerns and to actively contribute to global efforts to create a more sustainable and low-carbon future.

4. Conclusions and Policy Implications

This study analyzed the fundamental characteristics of China's low-carbon policies issued from 2007 to 2022, constructed the policy framework, and analyzed the policy topics and their evolutionary features. By providing a comprehensive analysis of China's low-carbon policy system, this study offers valuable insights for shaping future policies that promote sustainable development.

Results show that: firstly, China's low-carbon policies are categorized into three stages. ① Initial exploration stage (2007–2015): policies focus on energy conservation and carbon emission reduction, exploring measures for low-carbon development. ② Accelerated advancement stage (2016–2019): signing the Paris Agreement, promoting the construction of a carbon emissions trading system, and incorporating climate change into national strategic topics. ③ Comprehensive implementation stage (2020–2022): proposing carbon peak and carbon neutrality targets, releasing a series of significant energy-saving and emission reduction plans, and laying the foundation for sustainable development as a national strategy.

Secondly, the analysis of low-carbon policy topics reveals a gradual improvement in the systematization of policy construction, reflecting comprehensive government considerations in addressing climate change and sustainable development. China's "1 + N" policy system encompasses various key themes, and eight topics are identified: carbon emissions trading markets and regulatory mechanisms, energy conservation and emission reduction, circular economy and sustainable development, greenhouse gas detection and emission management, industrial low-carbon transformation, low-carbon technological innovation, sustainable urban planning and construction, and publicity, education, and social participation. The system spans multiple industries, including energy, industry, construction, transportation, and finance, indicating comprehensive coverage and industrial participation in policies.

Lastly, the evolutionary process of China's low-carbon policies demonstrates a gradual shift in policy focus and diversification of implementation methods. The initial stage emphasized environmental protection and energy conservation, followed by industrial adjustment and green transformation in the accelerated stage. The comprehensive implementation stage prioritizes carbon market construction and technological innovation, showcasing China's adaptive response to domestic and international environmental changes, and emphasizing sustainable development and a circular economy.

This study draws the following policy implications for green development. First, it appears appropriate for the government to follow a phased approach in policy formulation. The study shows that China's low-carbon policy has undergone three main stages. These stages reflect different development needs and strategies. Therefore, phased policy formulation can be flexibly adjusted according to specific development stages and needs, ensuring the effectiveness and adaptability of policies. Specific policies tailored to different development stages and needs allow for flexibility to adapt to changing circumstances over time. This phased approach is supported by the observed stages of policy evolution, which demonstrate how policies evolved from initial exploration to comprehensive implementation.

Second, strengthening interdepartmental collaboration is another path that seems beneficial. The complexity of low-carbon development, which involves sectors such as energy, industry, and transportation, necessitates coordinated efforts across multiple governmental

agencies. The study shows that key departments, including the National Development and Reform Commission (NDRC), the National Energy Administration, the Ministry of Ecology and Environment, the Ministry of Housing and Urban-Rural Development, the Ministry of Transport, and the Ministry of Finance, play significant roles in formulating and promoting China's low-carbon policies, demonstrating a high level of collaboration. For instance, the NDRC, as a leading department, collaborates frequently with other departments, such as the Ministry of Ecology and Environment and the Ministry of Transport. This coordination ensures policy consistency and effectiveness.

Third, emphasizing policy diversity and comprehensiveness is also effective. The evolution of China's low-carbon policies highlights a trend towards increasingly diverse and comprehensive measures. China's "1 + N" policy system exemplifies how diversified policy support across various sectors can comprehensively address climate challenges. The broad spectrum of policy topics, ranging from carbon market mechanisms to green finance, highlights the need for a multifaceted approach to low-carbon development. The evolution of policies shows a trend towards increasingly diverse and comprehensive measures.

Based on the findings, the study offers several policy recommendations. Firstly, in the exploration of low-carbon policy themes, green technology innovation is identified as one of the key themes. This shows that the government attaches special importance to technological innovation in low-carbon policy making and regards it as one of the key factors in achieving low-carbon goals. Secondly, one path that appears appropriate for the government to follow is refining the design and supervision of the carbon market to encourage companies to adopt more low-carbon production methods. Continuous improvements in market efficiency and effectiveness can support this goal. Thirdly, another suitable path for the government and financial institutions is to collaborate in promoting the development of sustainable financial products and services. Encouraging companies to make sustainable investments could significantly contribute to achieving low-carbon objectives. Lastly, strengthening environmental and low-carbon education and encouraging public participation in green actions can be effective strategies. The government can play a key role in enhancing awareness and motivating collective efforts to address climate challenges.

This study has several limitations. Firstly, it analyzes policies issued from 2007 to 2022, potentially excluding recent developments and trends in low-carbon strategies. The reliance on publicly available policy documents may miss informal or unpublished initiatives, and the varying quality of these documents can affect the analysis. Additionally, the study focuses on national policies, not extensively exploring regional or local variations within China, which could provide insights into distinct policy approaches and challenges. Future research could extend the analysis to include policies issued after 2022, providing insights into recent trends and adjustments. Additional data sources such as interviews with policymakers, case studies, and data from non-governmental organizations would offer a more comprehensive understanding of policy formulation and execution. Exploring regional and local policy variations could reveal unique challenges and successful strategies. Investigating the role of technological innovations in achieving low-carbon objectives, conducting international comparisons, and undertaking longitudinal studies to track the long-term impacts of low-carbon policies would also contribute valuable insights.

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