

Characterization, Evolution and Trends of Carbon Neutrality Based on CiteSpace

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Abstract: Since the 21st century, the concept of carbon neutrality has been paid attention to and promoted by more and more countries, and in-depth research on carbon neutrality can help to improve the environmental situation, which is of great special significance to the sustainable development of economy and society. In this paper, based on the carbon neutrality related literature included in the China Knowledge Network (CNKI) database from 2013 to 2022, we use the bibliometric software CiteSpace to visualize and analyze the literature in the field of carbon neutrality. The results show that: (1) from the point of view of the characteristics of publications, the research on carbon neutrality in China has seen an explosive growth after the proposal of the "double carbon" goal in 2020, and there are more inter-institutional and inter-authorship cooperation, without obvious research barriers. (2) From the perspective of research fields, carbon neutral research in China is roughly divided into 10 clusters, and most of the clusters have a high degree of overlap, and their related research has good continuity. (3) From the viewpoint of research hotspots, the field of carbon neutrality is roughly divided into three branches: green transition, financial instruments and low-carbon technology, and the research under each branch has a tendency of continuation and refinement.

Keywords: Carbon neutral, Bibliometrics, CiteSpace, Evolution.

1. Introduction

With the acceleration of global economic development and industrialization, the massive emission of greenhouse gases, mainly carbon dioxide, has triggered a series of environmental problems, such as rising global temperatures, rising sea levels, frequent occurrence of extreme weather, and declining crop yields, which have seriously threatened energy, resources, the economy, food security and other areas. In response to the many problems and adverse impacts brought about by the increasing changes in the global climate, the 2016 Paris Agreement proposes to contain the global temperature rise to 2°C above pre-industrial levels by the end of the 21st century, striving to achieve the temperature control target of 1.5°C. In order to achieve this temperature-control goal, the world needs to work together to realize net-zero carbon dioxide emissions by 2050, and "carbon neutrality" has been formally proposed in the context of this goal. As a responsible power, General Secretary Xi Jinping solemnly proposed a "dual-carbon" goal at the 75th session of the United Nations General Assembly: striving to achieve carbon peaking by 2030 and carbon neutrality by 2060.

The proposal of "double carbon" goal makes carbon neutral once become a new research hotspot in academia, some scholars have explored China's carbon emissions, carbon neutral, energy economy transition path based on the carbon neutral goal, Yu Biyin [1] used the independent research and development of the national energy technology and economic model (C3IAM/NET) to estimate the path of China's carbon emissions, and found that China's CO₂ emissions are expected to peak at about 10.8 billion tons in 2025, and energy-related CO₂ emissions will still exist in 2060, 300 million ~ 3.1 billion tons. emission pathway and found that China's CO₂ emissions are expected to peak in 2025, with a peak value of about 10.8 billion tons, and energy-related CO₂ emissions will still exist in 2060 at 300 million to 3.1 billion tons. Wang Can [2] analyzed the path to achieve carbon

neutrality and the corresponding policy system from the three levels of emission, technology, and society. Zhang Xiliang [3] (2022) used the global energy model (C-GEM) to explore the path of China's energy economy transition under the vision of carbon neutrality, and analyzed the uncertainty of the key characteristic indicators of the energy economy transition path. Some scholars analyze the challenges and opportunities faced by the coal [4], electricity [5], and natural gas [6] industries in the context of the carbon neutrality goal. Some scholars have also conducted research on related technologies involved in carbon neutrality, such as carbon dioxide capture, storage and utilization (CCUS), for example, measuring the total amount of forestry carbon sinks [7] and soil carbon sinks [8] in a certain region, as well as their corresponding evolutionary impacts and mechanisms.

Currently, there are different branches and research hotspots in carbon neutral research, and it is beneficial to sort out and explore the evolutionary trends and latest hotspots related to carbon neutral research to grasp the whole vein of carbon neutral research, which can provide scholars in this area of research with references and ideas to inspire them. Therefore, this paper uses CiteSpace software and the China Knowledge Network (CNKI) database as the data source to statistically analyze the literature records in the field of carbon neutrality in the past ten years from 2013 to 2022, and to show the development history, hotspot evolution trend and future development direction of carbon neutrality research in a visual form, so as to summarize and undertake carbon neutrality research in a stage-by-stage manner, and provide references and inspirations for future research in this field. In order to summarize and take over the research on carbon neutrality, and to provide reference and reference for future research in this field.

2. Research Methodology and Data Sources

2.1. Research methodology

This paper adopts CiteSpace 5.5.R2 software for bibliometrics and analysis, and uses visualization technology to clearly and intuitively display the cooperation network of authors and institutions as well as the co-occurrence network of keywords. The clustering of keywords scientifically sorts and categorizes different studies, and demonstrates the evolution and development trend of different clusters on the timeline, as well as the research hotspots contained in different time periods, which can bring practical and valuable references to disciplinary research, so that research scholars can more efficiently learn about the specific research areas, the correlations, and the new points of interest.

The specific research process of this paper is as follows:

First, all the literature containing carbon neutral research was precisely searched in CNKI, and the literature was screened and eliminated to finally obtain the basic data sources for the relevant analysis. Second, the statistical function of CiteSpace software was used to characterize the number of publications, journals, authors, and institutions, and visualization techniques were used to show the keyword co-occurrence network, keyword clustering, and the corresponding time-trend evolution law. Finally, the intellectual framework of carbon neutral research is derived, and the findings in the paper are summarized and discussed.

2.2. Data sources

In this paper, CNKI was used as the basic data source, the search time was December 24, 2022, the search time range was set as 2013-2022, the search was conducted in advanced search mode, the search items were topics, keywords and

titles, and the combination of the words "carbon neutral + net-zero emissions + zero carbon emissions" was used as the search term, and the precise search was conducted in the source categories including SCI source journals, EI source journals, NU core journals, CSSCI journals and CSCD journals. The source categories are SCI source journals, EI source journals, Peking University core journals, CSSCI journals and CSCD journals, and the preliminary search yielded 1,559 documents, excluding conferences, reports, notices, evaluations, journal introductions, etc., and finally yielded 1,493 papers as the basic data for the analysis of this paper.

3. Character Analysis

3.1. Number of articles issued

The annual number of papers issued in a specific research field and its changing trend can reflect the degree of attention of this research field [9]. Statistics on CNKI-exported literature found that China's research on carbon neutrality in the past decade has been in a trough before 2020, with the number of articles fluctuating within a very small range, while after 2020, the research on carbon neutrality has shown explosive growth, which is related to China's proposal of the "dual-carbon" goal in September 2020 at the United Nations' seventy-fifth general debate. This is related to the "dual-carbon" goal proposed by China at the 75th General Debate of the United Nations in September 2020. With the introduction of the "dual-carbon" goal, China's policies, industrial structure, energy structure, research and development (R&D) innovations have all been adjusted accordingly, and research related to the field of carbon neutrality has begun to become the latest research hotspot in recent years.

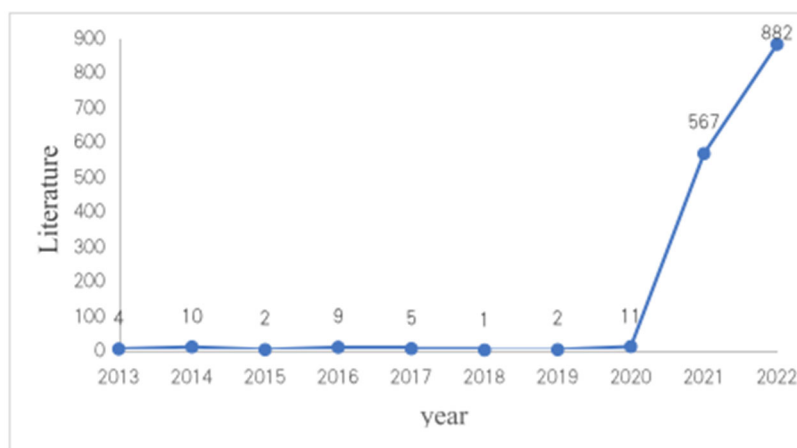


Figure 1. Quantitative characterization of the literature on carbon neutral studies

3.2. Journal distribution

Statistics on the publication status of journals in carbon neutral literature show that the journals with the largest publication volume are Environmental Protection, China Finance, Proceedings of the Chinese Academy of Sciences, and China Population-Resources and Environment, with publication volume of 73, 37, 35, and 29 articles respectively, and the composite impact factor of 2.972, 0.996, 5.904, and 7.598 respectively, among which China Population-Resources and Environment has the highest impact factor among the top ten journals in publication volume.

Environment is the journal with the highest impact factor among the top ten journals in terms of the number of articles issued. Finance in China is the second highest journal in terms of carbon neutrality in terms of the number of articles issued, indicating to some extent that environmental issues are linked to economic issues, and that the environmental Kuznet's curve is one of the major theoretical discoveries in this cross-cutting area. In response to environmental problems, in addition to the use of mandatory command environmental policies and regulatory instruments, the government prefers to use economic instruments to carry out macro-control and

economic incentives, which also promotes to a certain extent the intersection and integration of disciplines, academics in the more inclined to use the methods of economics to analyze, predict and empirically prove the correlation between the two,

so as to promote the adjustment and improvement of the environmental policy, so that China's Economic development and environmental issues are decoupled.

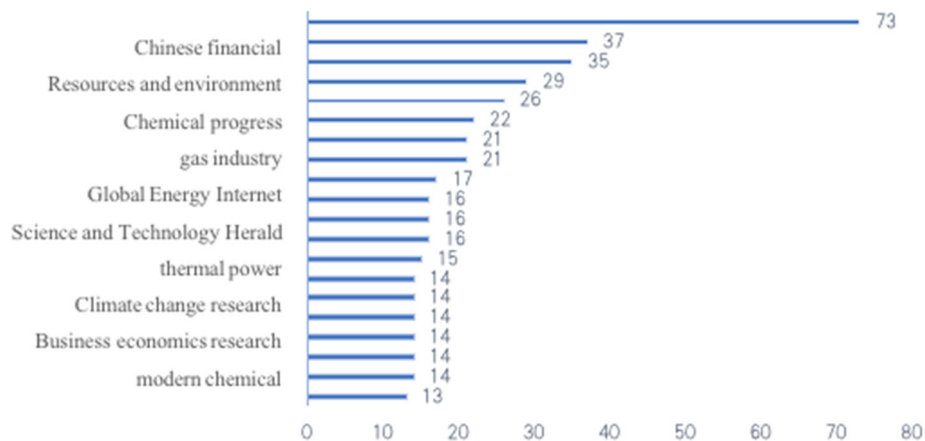


Figure 2. Distribution of publications in carbon neutral research journals

3.3. Distribution of institutional cooperation

From the viewpoint of institutional cooperation in carbon neutral research (Fig 3), universities and other research institutes are the main force in the field of carbon neutral research, especially those specialized in the field of environment. Among them, the university of the Chinese

Academy of Sciences (CAS) has the largest number of publications in the field of carbon neutrality, and the Institute of Geography and Resources of CAS alone has published more Chinese literature than most of the institutions in China. At the same time, research institutions in the field of carbon neutrality are not isolated, and there is a lot of cooperation among them, forming a number of cooperative networks.



Figure 3. Institutional collaborative network for carbon neutral research

4. Evolution of The Research Field

4.1. Field of research

Research clustering is a research theme formed by refining and summarizing on the basis of hotspot network mapping, which can intuitively show the main research areas. Its principle is to generate knowledge clusters through the spectral clustering algorithm, and to extract labeled topic words through the algorithm to characterize the

corresponding research frontier areas. In this paper, log-likelihood rate (LLR) data analysis method is used to extract the clustering labels, and all the literature is classified into 11 clustering units, which are carbon daze (#0), carbon neutral (#1), green finance (#2), energy transition (#3), carbon emission (#4), climate change (#5), anaerobic digestion (#6), carbon dioxide (#7), circular economy (#8), and carbon dioxide (#9). 7), circular economy (#8), systems engineering (#9), sustainability (#10).

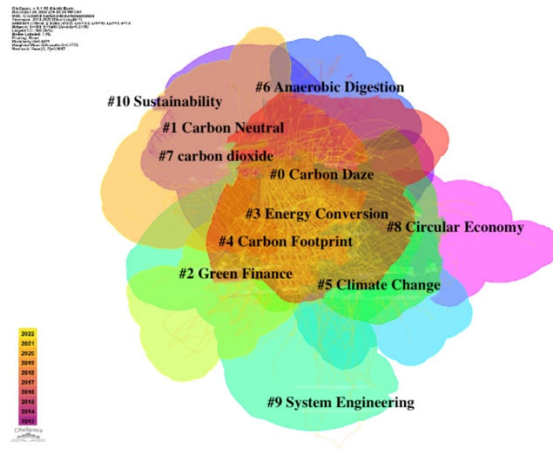


Figure 4. Cluster mapping for carbon neutral studies

As can be seen from Fig 4, carbon neutral research involves a wide range of fields, and the degree of connection between the clustering units varies. However, on the whole, the degree of stacking between the clustering units is higher, and the connection is closer, indicating that the co-citation phenomenon between the various clustering units is more common. The clustering map shows that the research concepts and methods of system engineering basically cover all the research processes in carbon neutral research, carbon emission and carbon peak are the two major themes in carbon neutral research, energy transition and circular economy are the necessary ways for carbon neutralization in China, and green finance is an important means for carbon neutralization in China.

historical research results of each clustering unit, the development trend over the years, and the relationship between clusters [10]. From Fig 5, most of the clustering units have good continuity so far and are in the prosperous period of development, except for the relative stagnation of the progress of anaerobic digestion and sustainability; among them, the literature scale of the clusters of systems engineering (#9) and energy transition (#3) is relatively larger, but the attention has been reduced in recent years, which is the result of the relatively small total amount of literature and a more decentralized focus of the recent research attention. In addition, there are relatively few links between circular economy (#8) and others, which need to be further strengthened in subsequent studies.

4.2. Trends in the evolution of research areas

The evolution timeline view (Timeline) can show the

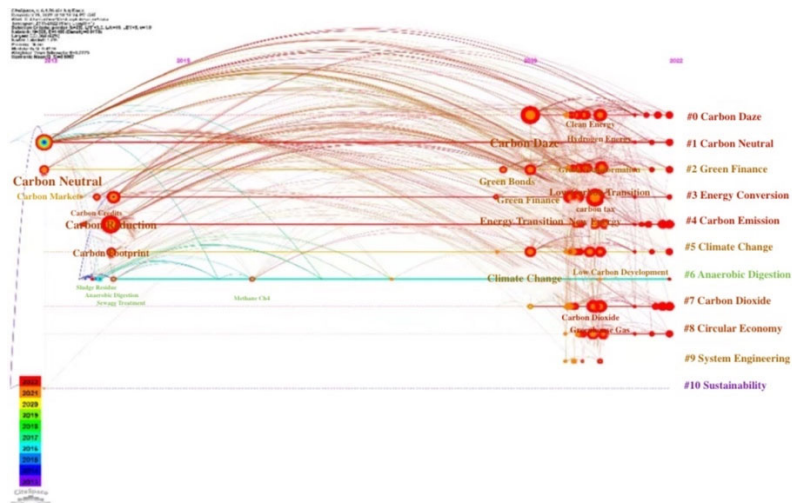


Figure 5. Keyword timeline knowledge map for carbon neutral research

5. Evolution of Research Hotspots

5.1. A hot topic of research

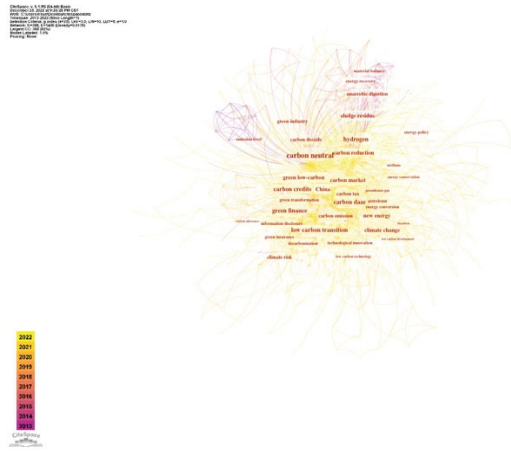


Figure 6. Keyword co-occurrence networks for carbon neutral research

In terms of keyword co-occurrence frequency, in addition to the keywords "carbon neutral", "carbon daze", "climate change", "carbon emissions", "carbon reduction" and "green finance", the most frequently occurring keywords are "energy transition", "green finance", "carbon emissions reduction", "energy transformation", and "green finance". In addition to "carbon neutral", "carbon peak", "climate change", "carbon emission", "carbon emission reduction" and "green finance", the keyword with the highest frequency of co-occurrence is "energy transition", "low carbon transition", "carbon sink",

"renewable energy", "new energy" (Table 1). In addition, "green development", "carbon tax", "high-quality development", "hydrogen energy", "greenhouse gases" also showed a certain degree of heat. In terms of keyword centrality, "carbon neutrality" and "green finance" are important nodes in the research hotspot network map, while "carbon peak", "carbon emissions" and "carbon tax" are important nodes in the research hotspot network map. emissions" and "carbon sinks" are secondary important nodes.

Table 1. Keyword centrality and co-occurrence frequency for carbon neutral research

| Number | Frequency | Centrality | Year | Keywords | Number | Frequency | Centrality | Year | Keywords |
|--------|-----------|------------|------|--------------------------|--------|-----------|------------|------|----------------------------------|
| 1 | 1229 | 0.55 | 2013 | carbon neutral | 22 | 18 | 0.03 | 2020 | global climate governance |
| 2 | 431 | 0.09 | 2020 | carbon daze | 23 | 18 | 0.00 | 2022 | "dual carbon" targets |
| 3 | 70 | 0.04 | 2020 | climate change | 24 | 17 | 0.04 | 2020 | addressing climate change |
| 4 | 65 | 0.09 | 2014 | carbon emission | 25 | 17 | 0.00 | 2021 | new power systems |
| 5 | 64 | 0.07 | 2014 | carbon reduction | 26 | 17 | 0.03 | 2021 | green and low carbon development |
| 6 | 56 | 0.17 | 2020 | green finance | 27 | 16 | 0.00 | 2022 | peak carbon neutral |
| 7 | 43 | 0.05 | 2020 | energy transition | 28 | 15 | 0.01 | 2021 | green credit |
| 8 | 40 | 0.03 | 2021 | Low carbon transition | 29 | 15 | 0.03 | 2021 | ecological civilization |
| 9 | 34 | 0.09 | 2014 | carbon credits | 30 | 15 | 0.02 | 2021 | low carbon economy |
| 10 | 31 | 0.00 | 2021 | renewable energy | 31 | 14 | 0.02 | 2021 | carbon trade |
| 11 | 30 | 0.02 | 2021 | new energy | 32 | 14 | 0.02 | 2014 | carbon emissions trading |
| 12 | 29 | 0.01 | 2021 | green development | 33 | 13 | 0.01 | 2021 | climate governance |
| 13 | 27 | 0.02 | 2021 | carbon tax | 34 | 12 | 0.01 | 2021 | ecological civilization |
| 14 | 26 | 0.02 | 2021 | high quality development | 35 | 12 | 0.00 | 2022 | low carbon development |
| 15 | 24 | 0.02 | 2021 | hydrogen | 36 | 12 | 0.00 | 2021 | ccus |
| 16 | 23 | 0.00 | 2021 | greenhouse gas | 37 | 11 | 0.00 | 2022 | energy conservation |
| 17 | 20 | 0.02 | 2021 | green transition | 38 | 11 | 0.01 | 2021 | green low-carbon |
| 18 | 20 | 0.07 | 2013 | carbon market | 39 | 11 | 0.00 | 2022 | clean energy |
| 19 | 19 | 0.01 | 2021 | carbon finance | 40 | 11 | 0.01 | 2021 | realization path |
| 20 | 19 | 0.01 | 2021 | carbon dioxide | 41 | 10 | 0.01 | 2022 | low carbon |
| 21 | 18 | 0.00 | 2021 | sustainability | 42 | 10 | 0.00 | 2022 | carbon pricing |

Analyzing the Top15 emergent keywords in the literature (Table 2), it can be seen that most of the emergent words began to appear in 2014, among which, the research hotspot on forest carbon sinks has continued to this day. 2020 double-carbon target is put forward, "zero-emission", "green recovery,

With the introduction of the dual-carbon goal in 2020, "zero emission", "green recovery" and "green bonds" have become mutated words and will continue to be hot research topics in the future. The above phenomena show that research on carbon neutrality has been gradually refined, and some of the research still maintains good continuity.

| Keywords | Year | Saliency | Initial year | Year of termination | 2013-2022 |
|------------------------|------|----------|--------------|---------------------|-----------|
| carbon offset | 2013 | 1.34 | 2013 | 2016 | |
| carbon emission | 2013 | 0.75 | 2013 | 2022 | |
| anaerobic digestion | 2014 | 4.68 | 2014 | 2018 | |
| sludge residue | 2014 | 4.01 | 2014 | 2018 | |
| sewage treatment | 2014 | 2.51 | 2014 | 2017 | |
| energy recovery | 2014 | 1.96 | 2014 | 2020 | |
| water source heat pump | 2014 | 1.33 | 2014 | 2018 | |
| carbon source | 2014 | 1.3 | 2014 | 2016 | |
| forest carbon sink | 2014 | 1.27 | 2014 | 2022 | |
| carbon footprint | 2014 | 1.19 | 2014 | 2016 | |
| carbon credits | 2014 | 0.76 | 2014 | 2016 | |
| residual heat | 2018 | 1.12 | 2018 | 2022 | |
| zero emission | 2020 | 1.41 | 2020 | 2022 | |
| green recovery | 2020 | 1.13 | 2020 | 2022 | |
| green bond | 2020 | 0.9 | 2020 | 2022 | |

6. Conclusion

In this paper, we derive the Chinese literature published in the field of carbon-neutral research in the past ten years from 2013-2022 from CNKI, analyze the changes in the number of articles published in the field of carbon-neutral research in the past ten years as well as the number of articles issued by journals, and present the authors' cooperation network, institutions' cooperation network, the co-occurrence network of keywords, the keyword clustering map, the timeline knowledge map, and the keywords' time zone view by using the visualization technology of the CiteSpace software. view to accurately grasp the development of the field and predict the research trends in the field.

Through the above research this paper mainly draws the following conclusions:

(1) In terms of characterization, the research on carbon neutrality was in a trough period from 2013 to 2019, and with the proposal of the "dual-carbon" goal in 2020, the relevant research in this field began to show explosive growth, and carbon neutrality-related research is a hot spot for the present and even for a long period of time in the future. Environmental Protection has published the largest amount of literature in this field, and China Population, Resources and Environment is the most influential journal in this field. Carbon neutrality does not have strong research boundaries, and researchers from different fields can carry out research together from the perspective of carbon neutrality to promote the development of the field of carbon neutrality research. Colleges and universities and other scientific research institutes are the main driving force of carbon neutrality research, with the Institute of Geography and Resource Studies of the Chinese Academy of Sciences as the representative.

(2) In terms of the evolution of research fields, the carbon neutral research field contains 10 clustering units, with a high degree of stacking among the clustering units, the phenomenon of co-citation is more common, and most of the clusters have good continuity so far.

(3) In terms of the evolution of research hotspots, the hotspots related to carbon neutral research have been

constantly refined, and can be roughly divided into three branches: green transition, financial instruments and low carbon technology, and the research under each branch has seen explosive growth in the past two years, and has a tendency of continuous refinement and continuation.

In view of the above research findings, this paper puts forward the following outlook on the future research related to carbon neutrality:

(1) Multidisciplinary integration. Carbon neutrality is a systematic and complex socio-economic and ecological issue, and the realization of this goal requires the participation of various fields. The resources and ecology of different countries and regions are very different, and institutions can realize targeted research in multiple regions through mutual cooperation. Increased multidisciplinary cooperation in research can help more industries to accelerate industrial reform, reduce carbon emissions in the production process, implement low-carbon production methods and achieve the goal of carbon neutrality more quickly.

(2) Emphasize the role of carbon offset technology in the goal of carbon neutrality. There are two ways to realize carbon neutrality: one is to use low-carbon and zero-carbon emission technologies, which is what most studies want to explore, to realize carbon neutrality by improving production technologies and reducing carbon emissions; the other is to carry out carbon offsetting, to offset the carbon dioxide produced by reducing carbon emissions in other places. Emphasis on carbon offsetting technology and multiple parallel channels can achieve the goal of carbon neutrality more efficiently. On the one hand, researchers explore the regional differences in carbon compensation rates in agriculture and other industries and their influencing factors, and coordinate the relationship between human activities and the ecological environment; on the other hand, they calculate regional carbon sinks and sources based on regional resources, and rationally formulate regional carbon compensation strategies to achieve low-carbon goals.

(3) Guiding carbon market construction. Carbon trading market is an important way to utilize the market mechanism to realize carbon emission reduction, but the smooth operation of the carbon trading market has high requirements

for all parties. For example, although China's carbon market construction has achieved certain results, there are still problems such as a large degree of dependence on CDM project transactions. Researchers can learn from the international mature carbon trading market to find solutions to the existing and possible future problems in the newly built carbon trading market, such as market regulation, quota allocation, etc., so as to guide the development of the carbon trading market from the theoretical point of view.

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