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Current status and bibliometric analysis of carbon emission reduction pathway research based on artificial intelligence and Web of science platforms

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ABSTRACT

Globally, tackling climate change and promoting low-carbon development has become a universally accepted course of action. self20century90Since the 1990s, human understanding of climate change has gradually deepened, and a scientific theoretical system and systematic governance framework have been constructed. In order to deeply understand the research status and development stage of carbon emission reduction path, this paper systematically combs and analyzes the relevant literature. This study was selected based on the Web of Science core collection database 2006 Year to 2023 Published by global scholars 8679 the English documents were used as research samples, and CiteSpace software was used to conduct an in-depth visual analysis of the number of published papers, the group of core authors, the distribution of research institutions, published journals, keywords and key areas of research. The results reveal that research in the field of carbon emissions in1991Before 200 years, it was still in its infancy, and then the number of literature increased year by year. The main research institutions are distributed in China, the United States and the United Kingdom, and the research in this field involves environmental science, engineering, environmental science, economics and other disciplines. In addition, climate change and energy development and rational utilization are the two major research hotspots in this field. The study results indicate that: (1) During the study period, the research of carbon emission reduction path received high attention, and the publication volume of relevant literature continued to increase and the growth rate increased significantly. (2) Through the analysis of the author group, it is found that a clear core author group has not been formed in the field of carbon emission reduction path. (3) The main research forces are concentrated in China, the United Kingdom, the United States and other countries, among which 13 research institutions including the Chinese Academy of Sciences and Tsinghua University have shown significant research ability and influence, and the cooperation between the research institutions and

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the authors is very close.(4) In terms of published journals, yes10The international journals show high attention to the field of carbon emission reduction, covering environmental science and ecology, energy and fuel, environmental engineering, economics and public management and other fields. Through the visual analysis of keywords, it is found that energy transition, microstructure research and carbon emission are the key objects of current research. Based on the analysis results and the actual situation, this paper puts forward the focus and direction of carbon emission reduction path research, aiming to provide theoretical and practical reference for the realization of carbon emission reduction targets.

Keywords: Carbon Emission Path, Web of science, Cluster Detection, Citespace

1. Introduction

With the serious consequences triggered by global warming and climate change, carbon emissions have been the focus of global attention, which is one of the main factors of the greenhouse effect and affects global warming, and carbon emission reduction is the action program proposed to meet this challenge [1-4]. Carbon emission reduction aims to reduce carbon emissions to mitigate the effects of global warming and climate change and to expand the capacity of public awareness and constructive action in all countries [5-7]. The increasing problem of global warming has led to the establishment of carbon emission reduction targets by various countries to ameliorate the problem of global warming, and carbon emission reduction targets define the reduction of carbon emissions that each country must achieve within a specified period of time [8-11]. They are a type of government-set environmental goals, but the goals may vary from country to country. In order to achieve carbon reduction targets, many countries have taken various measures, such as using renewable energy more efficiently, developing national carbon reduction plans, and setting up reciprocal incentive mechanisms to promote carbon reduction [12-15].

The carbon neutral goal is both an opportunity and a challenge, pointing out the direction for China's energy structure transformation and high-quality economic development, and at the same time, it will also carry the burden of long-term emission reduction tasks [16-17]. Under the vision of carbon neutrality, China will implement large-scale energy saving and emission reduction initiatives, intensify afforestation projects, levy carbon tax on small and medium-sized enterprises as well as trade in the national carbon market, and steadily realize the peak of carbon emissions [18-21]. On the basis of effectively curbing the year-on-year increase in carbon emissions, relying on scientific and technological innovation, improving energy efficiency, deeply exploring zero-carbon energy and renewable energy, and researching and developing negative-emission technologies, China's carbon emissions will gradually realize carbon neutrality along the path of the expected emission reduction targets [22-25].

Literature [26] examined the implementation paths and prospects of China's peak carbon and carbon neutrality based on the objectives and specific connotations of China's peak carbon and carbon neutrality, and pointed out that China's paths for realizing carbon neutrality include controlling carbon dioxide emissions, increasing the paths of carbon sinks, technological development, and policy formulation. Literature [27] analyzed the carbon emission reduction path to achieve carbon neutrality in the iron and steel industry, revealing that only further efforts in industrial structure, energy efficiency, and low-carbon technology can achieve a low-carbon transition. Literature [28] evaluates the emission reduction effect of the automotive industry in each province, optimizes the emission reduction pathways of the "lagging regions" that have not reached the industrial carbon reduction target, and draws a number of conclusions, including that "China has exceeded the 2020 industrial carbon reduction target". Literature [29] proposed a distributed robust optimization model to solve the low-carbon power scheduling problem, and discussed the scenario-based characterization of wind

power and the allocation method of initial carbon rights to solve the model, revealing the rationality and feasibility of the model, which takes into account the economy, environment and robustness of the power system. Literature [30] created a system dynamics model of carbon dioxide emission based on the relationship between the influencing factors of carbon dioxide emission and carbon emission reduction pathways, revealing that improving the energy structure is more helpful to reduce carbon dioxide emission than the economic growth rate and industrial structure optimization. Literature [31] estimated the impact of LCPP on urban CO2 using a multi-period difference-in-difference model to fill the gap in this field, showing that LCPP accelerates the process of CO2 emission reduction in China, provides a Chinese-specific method for limiting CO2 emissions and mitigating climate change, and is of great significance for advancing the low-carbon governance of cities. Literature [32] used a multi-objective planning approach to construct a low-cost pathway system model for achieving carbon neutrality in China, aiming to reduce costs, carbon dioxide emissions and air pollutants, emphasizing the importance of structural adjustment and emission control, and the approach has global applicability in achieving the key carbon emission reduction targets. Literature [33] adopted the super-efficiency DEA model and Malmquist index to assess the carbon emission efficiency values of the nine western provinces, and analyzed the factors affecting the carbon emission efficiency, and came to the conclusion that the overall CEE of the nine provinces is not high and there are significant inter-provincial differences. Literature [34] established a model of low-carbon sustainable development level of enterprises, illustrated that low-carbon economic efficiency, low-carbon technology stock and carbon dioxide emissions are indicators reflecting the low-carbon sustainable development level of enterprises, and pointed out that excessive government regulation would reduce the low-carbon economic efficiency of enterprises. Literature [35] examines the policy of green development of data centers and its driving role, and considers the application of green technology as an important strategy for energy-saving and low-carbon development of data centers, and summarizes the carbon reduction technologies in the areas of power supply and distribution system, intelligent operation and maintenance, and looks forward to the green development of data centers in the future into. Literature [36] compares the national paths and policies of China and the United States to achieve carbon neutrality, as well as the stage effects of carbon emission reduction in the two countries, mentioning that the policy systems of the two countries are diametrically opposed, and that China's transition time from peak carbon to carbon neutrality is shorter than that of the United States. Literature [37] explored China's provincial carbon emission reduction potential and emission reduction paths, pointing out that the development of regional carbon emission reduction paths can better promote the development of a green and low-carbon economy, and that China's carbon emission potential has been underestimated. The above studies analyzed the path of carbon emission reduction from the perspectives of enterprises, provinces, and countries, revealing that the paths to achieve carbon emission reduction mainly include policy formulation, R&D technology, etc., and demonstrated that China plays an important role in the field of carbon emission reduction and performs well overall.

This article mainly has the following innovations:

1) This study is the first time to conduct a bibliometric analysis of the development process of carbon emission reduction path research, comprehensively and objectively revealing the research status, hot spots and future development trend in this field.

2) In our research, taking time as the development line, we reveal how different carbon emission reduction paths can help a country achieve carbon emission reduction and guide economic and social practice.

3) By dividing the time period, we can determine the different priorities in the development of carbon emission reduction path research, and provide path inspiration for scholars of various countries.

2. Research Methodology and Data Sources

The data used in this study are all from the Web of Science literature database. We mainly collected the data from the following core databases, and the search keywords were focused on the carbon emission reduction path. Given that the carbon reduction path is a macro concept, therefore, related terms such as path, pathway and way are regarded as related topics.

Therefore, the main search keywords were "carbon emission reduction path", "carbon emission reduction measure" and "carbon emission reduction method". The search time was from 2005 to 2023, that was completed on December 31, 2023. We obtained a total of 8,679 search results using the following filters, covering the research directions of environmental science, green sustainable technology, engineering environment, environmental research, engineering, manufacturing, management, economics, finance, energy and fuel, interdisciplinary application of computer science, engineering chemistry, transportation science and technology, language (English). We used version 6.1R6 of CiteSpace software for quantitative analysis, using "topic + abstract + keyword" as the text to be analyzed by the software.

3. Descriptive statistics and quantitative analysis

3.1. Annual Growth of Journal Papers

When evaluating the research output of a field, besides the quality of articles, the degree to which articles are contributed, and the number of published articles, is also an important measure. The change in the number of articles can reflect the dynamics of the research process, and the increase of knowledge is positively correlated with the number of articles.

The research trend of the topic of carbon emission reduction can be seen from the number of published journals in Figure 1. Since 2005, the number of published papers has been increasing continuously. There were only 45 papers in 2005, and the growth was slow between 2005 and 2010, when the topic was not popular. In 2011, the World Meteorological Organization released the report "Global Climate Change 2010 - Ten Years of Climate Extreme Events", and the low carbon topic was paid more and more attention. In 2011, it reached 187 papers, and by 2020, it reached 1019 papers. The average annual growth rate of the number of journal papers was 25%, and it followed the regression curve ($R2=0.9758$, $p<0.05$). The explosive growth of the research on the topic also represents the awakening of the awareness of governments, related enterprises and ordinary people to the climate and environment problems. Carbon emission reduction is by no means an individual behavior or can be achieved by only one enterprise or one country, it requires global cooperation. In the analysis of the path of carbon emission reduction, only the action based on the concept of emission reduction can achieve sustainable high-quality development, and the achievement of the goal of carbon emission reduction requires complex and comprehensive basic theory. Since 2018, the difference between the cumulative value and the theoretical value of the papers and journals has gradually expanded, indicating that the research in this field is still in the stage of rapid development, and the speed of new discoveries is increasing.

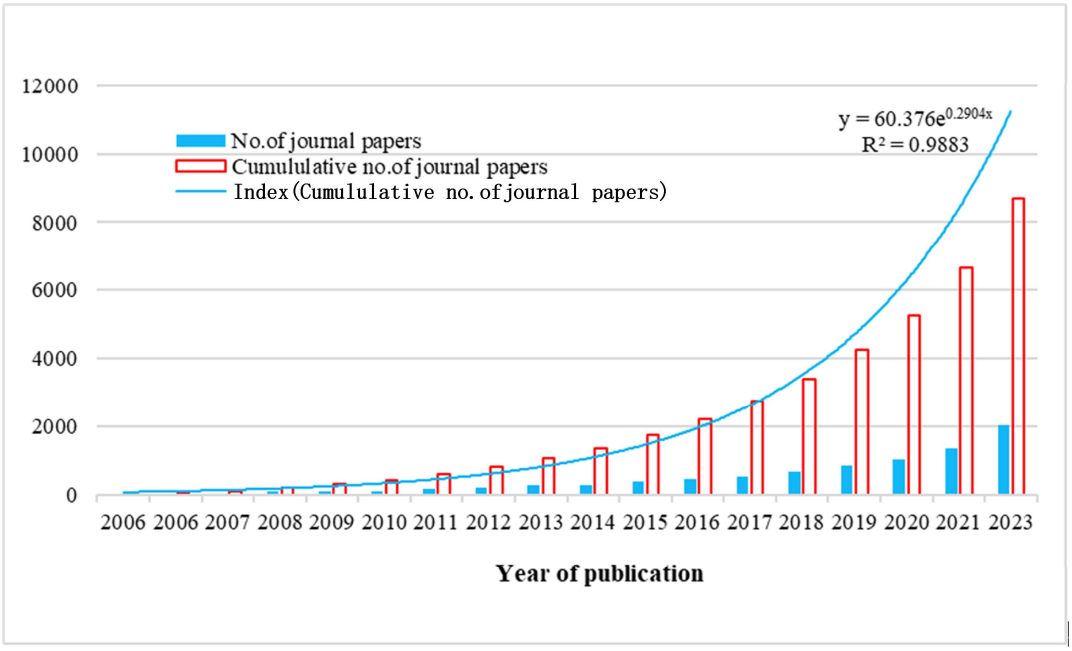

Fig. 1. Number of research literatures on carbon emission reduction path based on WOS

We divide the research on carbon emission reduction path into three stages (Figure 2). The number of published papers in 2005 was 45. Before 2005, the number of papers did not increase or decrease significantly, and this situation continued to change after 2009. From 2005 to 2010, we call this stage as the early stage of carbon emission reduction path research. From 2011 to 2016, the number of published papers on carbon emission reduction kept increasing, but the growth rate was similar to that of the previous stage, which maintained at about 150%. From 2017 to 2023, the research on carbon emission reduction path showed a rapid upward trend, with the growth rate reaching 287%, and the number of published papers each year exceeded 1000. We call this stage as the boom stage.

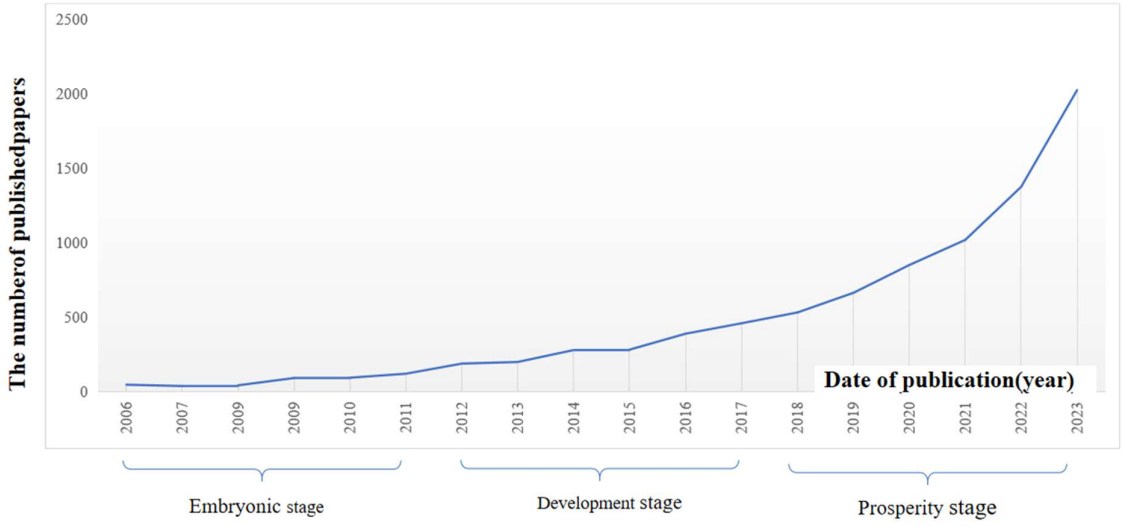

Fig. 2. Research on carbon emission reduction path based on the number of journal papers.

3.2. Author Analysis

3.2.1. Analysis of core authors. A total of 21507 authors were included in the 8679 journals retrieved. According to the calculation method of Price's law, the core author group was analyzed. Zhang Y, who published the most papers, published 84 papers in total. Therefore:

Where represents the lowest number of publications according to Price's Law and represents the highest number of publications in the field.

$$M_P = 0.749\sqrt{N_P} \tag{1}$$

Therefore, 7 or more publications are determined as core author candidates.

Then, according to the lowest total citation times, in the field of Then, according to the lowest total citation times, in the field of carbon emission reduction path, Wang, Dongwu has the highest total citation times, with a total of 5686 times. The calculation formula is as follows:

$$M_S = 0.749\sqrt{N_e} \tag{2}$$

Where represents the lowest number of publications according to Price's Law, and represents the highest number of publications in the field.

Therefore, those who were cited 56 times or more were identified as core author candidates.

Finally, authors who meet the above two conditions are screened out, and 479 core author candidates in the field of carbon emission reduction paths are were identified, with a total of 3527 publications and 82,404 citations (without excluding self-citations).

3.2.2. Establishment of Composite Index. The average number of publications and average citations of 479 core author candidates were calculated according to:

$$\overline{X} = \frac{X_S}{n} \tag{3}$$

$$\overline{Y} = \frac{Y_S}{n} \tag{4}$$

Where, represents the total number of publications of core author candidates in the field of carbon emission reduction path, represents their total citation frequency, and n represents the number of people. Therefore, the average number of publications is 7, and the average citation frequency is 172.03.

The composite index function is constructed using the number of publications and citations, and the composite index number of each author is calculated to obtain the final core author group. The formula is:

$$Z_i = \frac{X_i}{\overline{X}} \times 0.5 + \frac{Y_i}{\overline{Y}} \times 0.5 \tag{5}$$

Where, represents the comprehensive index number of the candidate core author i, represents the total number of publications, and represents the total number of citations. The coefficients of publications and citations are both 0.5.

As shown in Table 1. Through the calculation of the comprehensive index of 479 core author candidates, the top 11 core authors with a comprehensive index of more than 2 are obtained. Their total number of publications is 530, accounting for 15% of the total number of articles in the research on carbon emission reduction paths, which is a large gap from the standard of 50% in Price's law, which also indicates that the current research in this field has not formed a fixed core author group. Although Li J has only 40 publications, his citation times can reach 6092, and his comprehensive index reaches 20.56. His article "Coastal Haze Pollution, Economic and Financial Performance, and Sustainable Transformation in Coastal Cities" published in 2020 has a citation number of 5698, which is worthy of attention. Zhang Yan, who ranks second in the comprehensive index, has 84 publications,

the largest number of articles, and his citation times are also 1257, and his comprehensive index is 9.65.

Table 1. Ranking of the top 11 core authors. Si represents the author's composite evaluation index based on equation (5)

Rank	Journal	No. of journal papers	Number of Citations	Proportion of total (%)
1	Li J	40	6092	20.56
2	Zhang Y	84	1257	9.65
3	Wang Y	66	1440	8.90
4	Lei Y	66	1092	7.88
5	Geng Yong	64	947	7.32
6	Zhang XL	39	1287	6.53
7	Zhang X	40	1199	6.34
8	Yang J	45	1052	5.71
9	Wang W	42	859	5.50
10	Dong F	40	576	4.53
11	Chen B	39	536	4.34

The relationship network among authors can be clearly presented by citespace software, and the size of the circle in the center of the node represents the number of published papers, the larger the circle, the more published papers. In addition, there are connections between each node, indicating the frequency of cooperation, the thicker the connections, the closer the cooperation, and the more frequent the cooperation. The results are shown in Figure 3, forming a large radially shaped research cooperation team, formed around several central authors such as Wang Peng, Geng Yong, Zhang Fan, and there are also some small research teams, such as Sovavool, Wei Yi-Ming, Dong Feng, and there is certain cooperation and contact between these small teams and the central team. Although there is no stable core author group in this field, it is in a stage of rapid development, so the research in this field can be further deepened and resource sharing and cooperation can be strengthened.

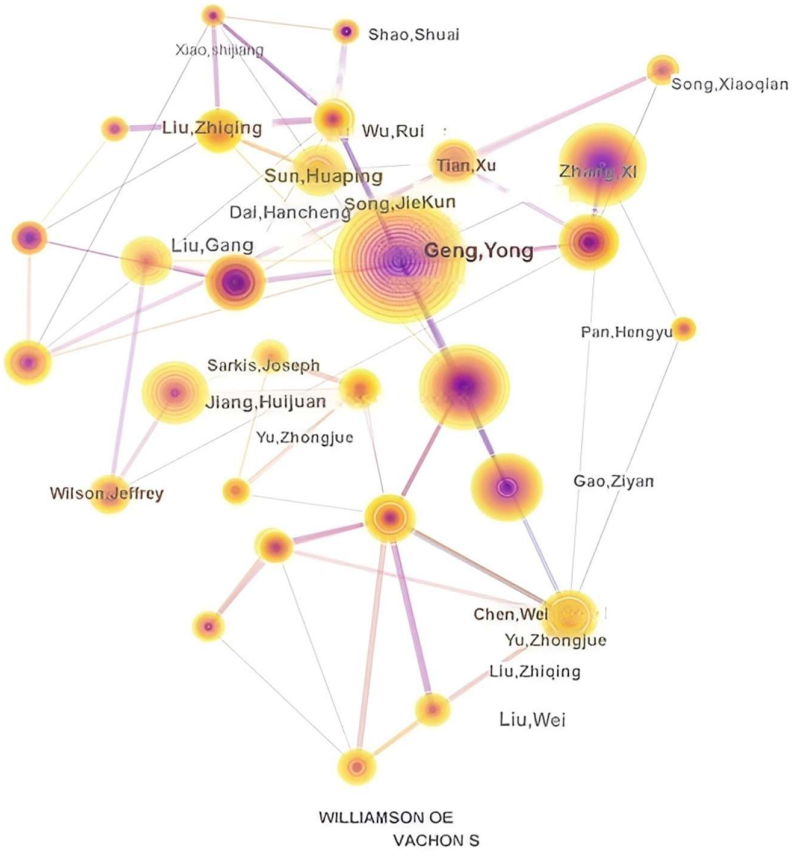

Fig. 3. Author cooperation diagram produced by the CiteSpace software

3.3. Analysis of affiliated research institutions

This paper analyzes the high-output research institutions and their cooperative institutions in the field of carbon emission reduction paths, discusses the current research status and cooperation, and looks forward to the future development direction of cooperation between institutions.

Among many research institutions, the Chinese Academy of Sciences ranks first with 375 published papers and 10,937 citations. The University of California has the highest citation frequency per paper, with 111 published papers, but the average citation frequency is as high as 74.35 times per paper, with authoritative and advanced research results in the field of carbon emission reduction paths. The University of California has a large university system, with many advanced researches in the fields of biology, chemistry, environment and materials, which are published in top journals. It has an advanced energy and environmental materials team, has also established the Energy Foundation, the Prospective Carbon Neutrality Strategy Research Institute, and has carried out research cooperation with many internationally renowned universities, and has practiced to reduce fossil fuels in the operation of the university.

Among the top 13 research institutions with the highest number of publications, through summary analysis, we can see in the Figure 4 that the cooperation relationship between institutions is relatively simple, most of which are universities or research institutes, with less cooperation with enterprises and government departments. Many researches on carbon emission reduction paths and low-carbon development remain at the theoretical level. Taking the Chinese Academy of Sciences with the highest number of publications as an example, its cooperation is mostly with the university and its subordinate research institutes, followed by Beijing University of Aeronautics and Astronautics, Tsinghua University, Sun Yat-sen University, etc.

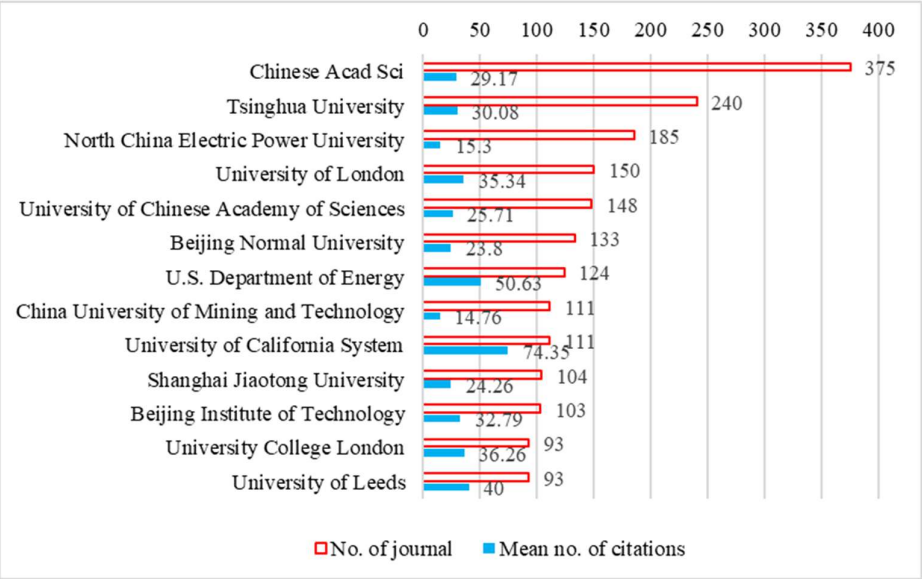

Fig. 4. Core research institutions and their publication number and frequency of citations

Table 2 reveals the top 13 research institutions, literature proportion and mutual cooperation of supply chain coordination management research. Through summary, we find that the cooperation network is relatively simple, mostly concentrated in universities and research institutes, with less cooperation with enterprises, indicating that the current supply chain coordination management is only at the theoretical level. The Chinese Academy of Sciences ranks first in terms of the number of publications, and the University of California has the highest average citation times, and its cooperation network involves various branch systems within its system and the University of San Diego, etc. In addition, North China Electric Power University, University of London, Beijing Normal University, Department of Energy of the United States, China University of Mining and Technology, Shanghai Jiao Tong University, Beijing Institute of Technology, University College London, and Leeds University all have an important impact on the research and development of carbon emission reduction paths.

Table 2. Core research institutions and their cooperation networks

Item	Research institutions	The number of papers published	Proportion	Research institutions with cooperative relations
1	Chinese Acad Sci	375	4.32%	Institute of Geographical Sciences CAS, Natural Resources Research CAS
2	Tsinghua University	240	2.77%	Chinese Academy of Sciences; U.S. Department of Energy
3	North China Electric Power University	185	2.13%	Zhejiang University, Hong Kong University of Science and Technology
4	University of London	150	1.73%	London School of Economics and Political Science; King's College London
5	University of Chinese Academy of Sciences	148	1.71%	Beihang University, Xinjiang Institute of Ecology
6	Beijing Normal University	133	1.53%	Tianjin University, Institute of Geographical Sciences CAS
7	U.S. Department of Energy	124	1.43%	Pacific Northwest National Laboratory, International Institute for Applied Systems Analysis
8	China University of Mining and Technology	111	1.27%	Jiangsu Normal University, Chinese Acad Sci, Ministry of Science and Technology
9	University of California System	111	1.27%	San Diego State University, California Institute of Technology
10	Shanghai Jiaotong University	104	1.19%	Shanghai Bureau of Ecological Environment, Shanghai University of Finance and Economics, Japan National Institute for Environmental Research
11	Beijing Institute of Technology	103	1.18%	Sustainable Devresinstecon Soc Beijing, Beijing key lab energy Econenvironm Management
12	University College London	93	1.07%	Imperial College London, University of London
13	University of Leeds	93	1.07%	University of Sussex, University of Edinburgh

3.4. Analysis of literature sources and research areas

After summarizing 8679 literatures in the field of carbon emission reduction path, it is found that 358 journals are more concerned about the research of carbon emission reduction path, while 1321 journals only have less than or equal to three papers published on this topic. Among the 358 journals that are more concerned about the research of carbon emission reduction path, the number of published papers is also quite different. Therefore, according to the Bradford's law, the above journals are divided into core area, relevant area and non-relevant area according to the number of papers published in this research field. The Bradford's law calculates the core area, that is, where Q is the number of core area, E is the Euler coefficient, and P is the maximum number of papers published by the journal. Therefore, in this field, $Q=2\mathrm{In}(eE\cdot 537)=13.73$, so more than 13 papers can be published.

As can be seen from Table 3, the number of journals in the core area is 106, and the total number of published papers has reached 5321, accounting for 61.27% of all the literature retrieved. At the same time, the citation report database partition of the above journals is located in Q1 and Q2, among which there are no lack of high-quality journals such as Journal of Cleaner Production and Renewable Sustainable Energy Reviews, among which the number of published papers of Journal of Cleaner Production ranks first, with 537 papers published in total from 2005 to 2022, accounting for 6.18%. In the research of carbon emission reduction path, most journals' article research is in-depth and

innovative, and is still in the development stage in terms of quantity and quality, with room for growth in the future. The research of carbon emission reduction path mainly focuses on environmental science and ecology, energy and fuel, environmental engineering, economics and public administration.

Table 3. The 10 core journals

Item	Source Publication	Number of Records	Research Areas	JCR Partition	Proportion
1	INTERNATIONAL JOURNAL OF PRODUCTION ECONOMICS	568	Decision Sciences	Q1	9.90%
2	INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH	360	Management Science and Operations Research	Q1	6.26%
3	EUROPEAN JOURNAL OF OPERATIONAL RESEARCH	353	Decision Sciences	Q1	6.14%
4	JOURNAL OF CLEANER PRODUCTION	314	Environmental Science	Q1	5.46%
5	SUSTAINABILITY	275	Environmental Sciences& Ecology	Q2	4.78%
6	COMPUTERS INDUSTRIAL ENGINEERING	235	Engineering	Q1	4.09%
7	PRODUCTION AND OPERATIONS MANAGEMENT	151	Engineering	Q1	2.63%
8	TRANSPORTATION RESEARCH PART E LOGISTICS AND TRANSPORTATION REVIEW	140	Operations Research and Management Science	Q2	2.44%
9	PRODUCTION PLANNING CONTROL	128	Management Science	Q2	2.23%
10	ANNALS OF OPERATIONS RESEARCH	115	Decision Sciences	Q2	2.01%

4. Research hotspots

4.1. Visual Analysis of Keywords

In order to comprehensively and deeply analyze the history and development status of the research on carbon emission reduction path, we use CiteSpace to conduct visual analysis on the keywords of the retrieved journal papers to identify the research hotspots in this field. Figure 5 shows the resulting key word co-occurrence map for journal papers from 2005 to 2023.

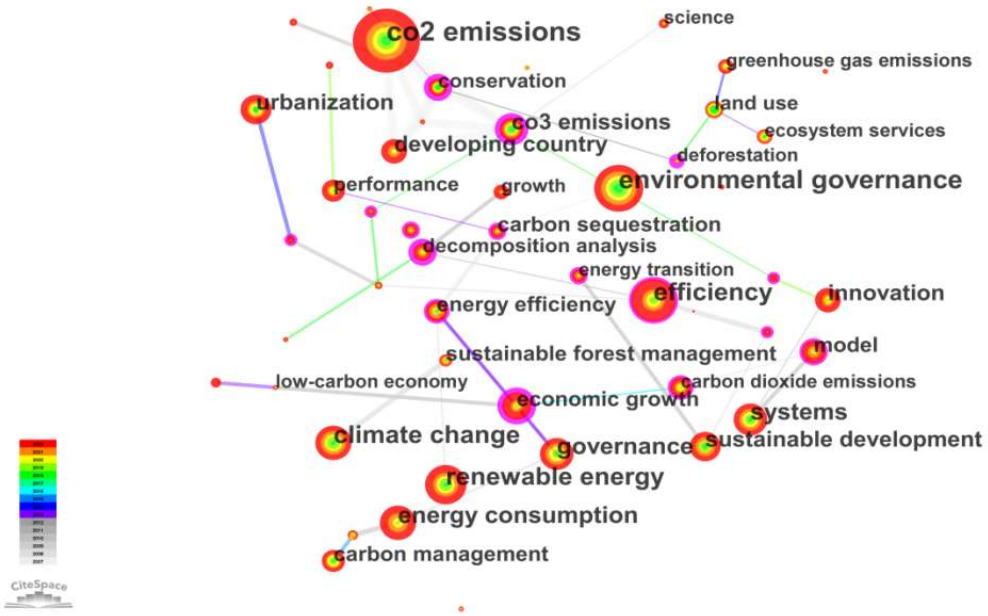

Fig. 5. Keyword co-occurrence map based on the CiteSpace analysis

The size of the displayed node in the figure is positively related to the frequency of occurrence, that is, the larger the node, the higher the frequency of occurrence, so we can see some top-ranked keywords, such as: co2 emission (1046), efficiency (819), environmental governance (662), renewable energy (651), climate change (635), energy consumption (546) Wait. Generally speaking, the study of carbon emission reduction path is related to energy consumption and climate change, which is also in line with the law of global economic and social development. All countries are taking active and powerful measures in emission reduction actions. A new virtuous circular development model is gradually maturing, and carbon emission reduction is the improvement of economic competitiveness, social benign development and ecology. Multiple collaborative governance of environmental improvement plays an important role.5.

4.2. Cluster analysis of high-frequency keywords

By using citespace software to cluster the high-frequency keywords of supply chain coordination management research, as is shown in Table 4.

In general, keywords for carbon emission reduction path research can be classified into the following six categories after clustering, namely, energy transition (#0), microstructure research (#1), carbon emissions (#2), carbon emission change (#3), low-carbon supply chain (#4), and carbon absorption (#5).

In cluster analysis, energy transition includes 188 keywords, and the core keywords focus on energy transformation, renewable energy, sustainable development transformation, multi-level perspective analysis, and energy fairness. There are 180 keywords in the microstructure research category, and the core research focuses on the production of carbon emission reduction in heavy industries such as steel, including mechanical performance research, microstructure evolution process, strengthening mechanism, low-carbon steel, and continuous serious plastic problems. The cluster capacity of carbon emissions has reached 177, and the research mainly emphasize carbon dioxide emissions, space spillover, carbon finance, impact mechanism, and industrial structure adjustment. The number of clusters of carbon emission changes has reached 170, mainly including climate change, carbon emissions, sustainable development, life cycle assessment, and economic feasibility analysis. The low-carbon supply chain contains 140 keywords, focusing on low-carbon economy, input-output analysis, heating industry, pm2.5, low-carbon performance and other research. The carbon absorption capacity

is 52, which also shows the frontier of the field. The core research focuses on carbon storage, organic carbon, environmental protection, industrial energy efficiency and energy conservation evaluation.

Silhouette is the silhouette degree, indicating the degree of homogeneity of internal keywords after clustering, that is, the correlation. When the Silhouette value is about 0.7, the degree of homogeneity is higher. Among the six categories, the internal qualitative presentation data of various types is better, especially in terms of energy transition and carbon sink, the value has exceeded 0.9. Mean (year) represents the average year in which clustering keywords appear, with low carbon supply chain and carbon sink averaging 2018 and 2017, respectively. The year of vocabulary is relatively new and the degree of cutting-edge is high.

Table 4. Keyword clustering results for the journal papers on carbon emission reduction path in the Web of Science database from 2005 to 2023

Cluster number	Cluster label	Size	Silhouette	Mean (year)	Main research focus
#0	energy transition	188	0.90	2015	energy transition; renewable energy; sustainability transitions; multi-level perspective; energy justice
#1	Micro-structure	180	0.72	2009	mechanical properties; microstructural evolution; strengthening mechanism; low carbon steel; continuous severe plastic deformation
#2	carbon emissions	177	0.73	2017	co_2 emissions; spatial spillover; digital finance; impact mechanism; industrial restructuring
#3	carbon change	170	0.71	2014	climate change; carbon emissions; sustainable development; life cycle assessment; economic viability analysis
#4	Low-carbon supply chain	140	0.78	2018	low-carbon economy; input-output analysis; heating industry; pm2.5; low-carbon performance
#5	carbon sink	52	0.91	2017	carbon sequestration; organic carbon; conservation; industrial energy efficiency; energy savings assessment

4.3. Evolution of research trends

Through the above analysis, there is a certain analysis of research institutions, research hotspots and other aspects in the field of carbon emission reduction path research. In terms of future development trends in this field, it is also necessary to use citespace software to analyze the carbon emission reduction path for timeline chart analysis and space-time view, according to the above division of the development stage. As shown in the Figure 6, from the initial germination period (2005-2010) to the gradual development (2011-2016), and then to the current boom period (2017-2023), it shows the dynamic evolution process in the field of carbon emission reduction path in an all-round way. Because the original sample size of the data is large, after refining and screening, the literature with low relevance in the sample is screened out, and the total amount of data is reduced to 4768, from 2007 to 2023.

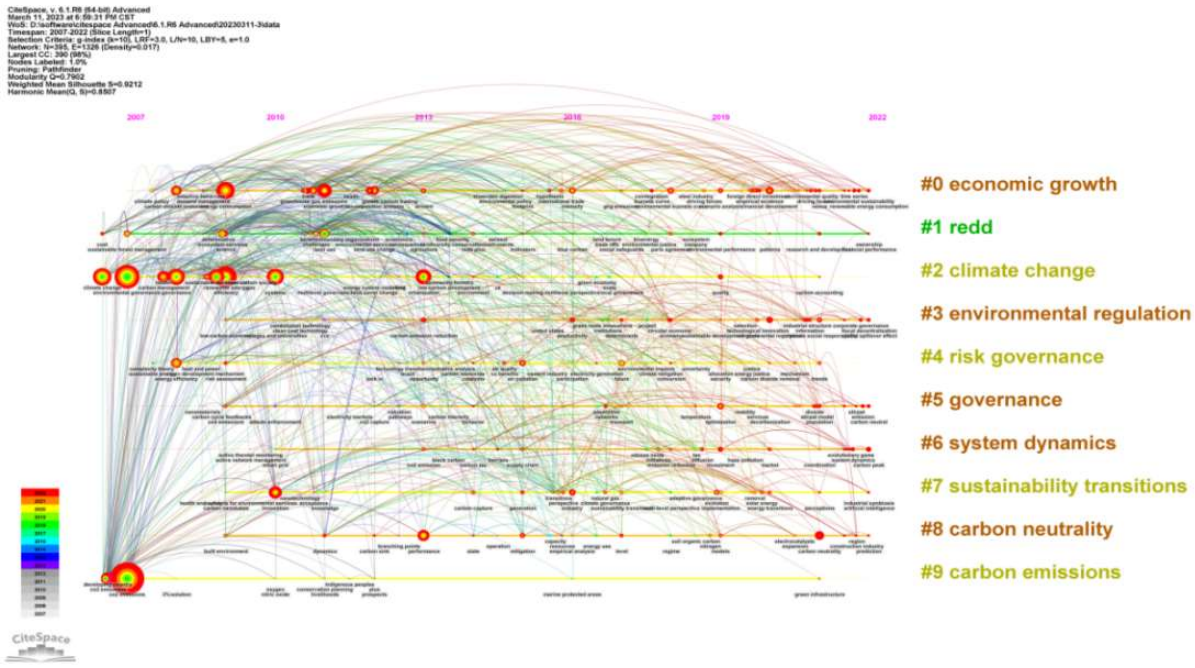

Fig. 6. Timeline chart of carbon emission reduction path research

From the literature research, it can be seen that in the graph drawing, in the past, we often used time zone maps for analysis and research. After the upgrade of citespace software, the current timeline graph is increasingly used in trend research. The timeline graph can not only pay attention to the clustering situation, but also make it more convenient to operate. From Figure 7, the carbon emission reduction path has developed since 2005, and the cluster keywords generated on the right side of the map are more detailed and more specific. At the same time, many keywords are concentrated in the germination stage from 2005 to 20010, and some important nodes include: renewable energy, mechanical properties evolution, economic growth, co2 emissions, climate change, etc. These keywords are not only closely related, but also have a long time span. Keywords also show that in the study of carbon emission reduction paths, most of them are developed on the basis of the previous one. From 2011 to 2016, the frequency of keywords in the timeline map decreased, and in the context of "double carbon" from 2017 to 2022, new words emerged.

In the time zone map, based on the keyword hotspot analysis and cluster analysis, the future development trend of carbon emission reduction paths is shown in the following aspects:

1) The technical support of the carbon emission reduction path and the standardized policy guidance of the carbon emission reduction path complement and promote each other. Technology and standardization are also the two basic goals of the development of carbon emission reduction path.

2) The carbon emission reduction collaborative governance model will integrate new technologies into a hot spot for future research. It is likely to become the hot spots of carbon emission reduction innovation in the future. Carbon finance, carbon market construction, carbon tax, renewable energy technology and other methods in the field have a high degree of center and frequency in the co-analysis of keywords in this field.

3) Multi-field overlap, multi-disciplinary interdisciplinary. At present, the research stage of carbon emission reduction path involves climate governance. In addition, there are application prospects in many fields, such as industry, finance, energy and other industries closely related to the public.

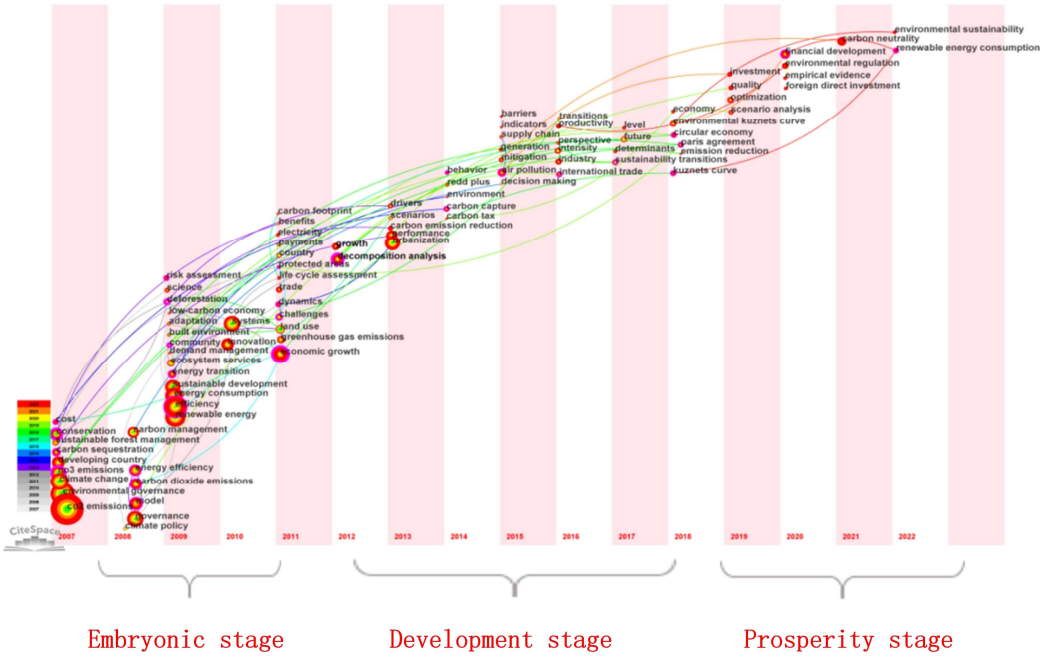

Fig. 7. Timetone view for carbon emission reduction path research

5. Time perspective on carbon emission reduction path research

5.1. Early stage (2006-2011)

Since the completion of the two industrial revolutions, the development of the world economy and the rapid expansion of the total population have accelerated the emission of carbon dioxide and emissions, especially the entry 20. After the 19th century, excessive energy consumption and fossil fuel combustion make the problem of climate pollution, and gradually become the focus of many countries and even the world. 2005.2.16, the Kyoto Protocol came into force on Monday, the first international bill in human history to limit greenhouse gas emissions. The protocol aims to stabilize the atmospheric content of greenhouse gases at an appropriate level to prevent dramatic climate change from harming humans. It marks the beginning of the carbon emissions restriction regulations and sets the stage for subsequent international climate agreements. Therefore, in the early stage of the development of carbon emission reduction path, industries and industries with more carbon emissions began to focus on how to reduce emissions by improving emission patterns. Under the influence of factors such as cost and price, this behavior cannot effectively and sustainably reduce global carbon dioxide emissions. International research on carbon dioxide emission reduction has attracted wide attention and discussion, and many new concepts have come into being.

5.2. Development period (2011-2016)

With the development of economy and society, in the choice of carbon emission reduction path, the emission reduction parties and increasingly realize that the behavior of a single party is difficult to produce good emission reduction effects, and only the members of the system can achieve the emission reduction target. Therefore, with the research of energy consumption, related concepts are gradually put forward, such as international climate agreement, carbon trading market construction, carbon tax, vegetation restoration, agricultural reform, energy policy, this stage of the research topic more widely, not only limited to the field of fuel, also expand to the field of ecological environment science, and closely combined with economic sustainable development. At this stage, the academic research on carbon emission reduction path mostly stays at the macro level, but to some extent greatly

promoted the depth of carbon emission reduction thought. The establishment of the Paris Agreement, as a2015The important milestone in the 2000 global climate change campaign not only promoted the global climate governance process, but also brought new impetus and direction to carbon emission reduction research. Scholars found in the research that the carbon emissions of express delivery industry increased in five years200% The fact is that transportation is the main source of carbon emissions, and its emission reduction becomes the key. In addition, China's carbon emissions increased in the second quarter10%, the increase in coal power and transportation is the main reason. The growth of global carbon emissions also shows the challenge of emission reduction targets. As a result, effective carbon emission reduction cooperation, as well as the potential of AI and other technologies, has become the focus of global attention, with a significant increase in the number and direction of relevant research.

5.3. Prosperity Period (2017-2023)

Since the formulation of the Paris Agreement, many countries have announced their own carbon reduction targets and realization dates on different occasions, which has once again stimulated researchers to explore the issue of carbon emission reduction. During this period, the number of research articles on carbon emission reduction path showed a rapid rising trend. The reason is that many countries and regions have also incorporated the target of carbon emission reduction into a strict legal framework, which lays a strong foundation for greenhouse gas emission reduction actions and supporting system design, which also brings carbon emission reduction to the level of national strategy, and scholars have begun to explore the path of carbon emission reduction from different perspectives. However, due to the differences in national conditions, the research and implementation focus of carbon emission reduction are different, but in the study, we can see that the development of low carbon economy must be guaranteed by system, maximizing the environmental and economic benefits are the difficulties and priorities; and technology is the foundation, in the process of optimizing energy and industrial structure, only the practical, economically affordable zero carbon, low carbon and decarbonization technology can make carbon reduction. Previous studies on carbon emission have mainly used traditional statistical models for empirical analysis, such as input-output model, spatial panel model, CGE model, and SDA model. 2020In 2000, after Xi Jinping proposed China's emission reduction target at the 75th General Assembly of the United Nations, many Chinese scholars showed great enthusiasm for carbon emission reduction research, and high-quality papers emerged. Scholars at home and abroad have conducted in-depth discussions on practical problems and put forward suggestions on improving laws and regulations, aiming to jointly promote the realization of carbon emission reduction targets through management means and market mechanisms. In general, the research context of carbon emission reduction path in this period is increasingly clear, the research content and scope are constantly expanding, and more attention is paid to the practical application of research results.

6. Conclusions and future research prospects

This paper systematically reviews the relevant literature of carbon emission reduction path research. On this basis, charts and knowledge maps are used to intuitively show the number of publications, core authors, research institutions, source journals, research hotspots and future development direction of carbon emission reduction and sustainability research. Through research, we found that:

1) According to the bibliometric analysis,1970-2015.The number of papers in the field of carbon emission has increased year by year, indicating that the number of papers on carbon emission reduction path research has increased exponentially. And the core research in this field we have learned from after the Kyoto Agreement came into force2006It began to record in 2000, and then experienced three development stages: early stage, development period and prosperous period.

2) From the perspective of core author clues, the influential literature mainly comes from a few authors, such as LiJ, Zhang Y, Wang Y, LiuY, LiY, etc11A core author.

3) From the perspective of research institutions, according to the average number of citation times and the number of publications, the most influential institutions in this field are Hong Kong Polytech University, followed by Tianjin University Chinese Academy of Sciences, South China University of Technology, University of Electronic Science and Technology of China.

4) From the source journal clues, the field of carbon emission reduction path research has been published recently1500Seed journals, among them10The different journals are located in the core area of this paper, such as INTERNATIONAL JOURNAL OF PRODUCTION ECONOMICS, INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH, EUROPEAN JOURNAL OF OPERATIONAL RESEARCH, JOURNAL OF CLEANER PRODUCTION, SUSTAINABILITY, etc. It also involves green and sustainable energy, energy efficiency technology, new energy and digital big data technology and other topics.

5) Carbon emission reduction has become the most frequently appeared keyword in the field, which echoes the carbon peak and carbon neutral targets proposed in the government work report, highlighting the importance of carbon emission reduction strategy research. Research topics also include the impact of carbon emissions, climate change, energy and other topics, which are closely related to the carbon emission reduction strategy in the construction stage, carbon emission mechanism design and emission reduction path analysis, and the progress and trend of regional carbon emission research. For the future problem of carbon reduction research must be combined with advanced technology, technology is the advanced productivity of carbon emissions, this is a fundamental transformation of the development mode, is also a revolutionary change of energy economic system, to gradually form to slow and adapt to climate change energy structure, industrial structure and production and way of life.

However, the study of carbon emission reduction path also has some shortcomings. For example, most emission reduction technologies are still in the early stage of development, which needs to rely on policy support and effective cultivation of the market environment. However, the current research still lacks in-depth discussion on the practical, feasible and cost-effective carbon emission reduction schemes for the complementary integration of 'technology + management + market'. In addition, there is a lack of research on the carbon emission reduction path of multi-subject participation in governance. In fact, there are diversified stakeholders in carbon emission reduction, and there is more space for cooperation in the practice of carbon emission reduction. In addition, the future research on carbon emission reduction path should also consider the interdisciplinary integration of natural science and social science, such as energy, economy, environment, finance, education and management. Only with policy guidance, market and technology simultaneously, and multidisciplinary integration, can we make steady progress towards the goal of carbon emission reduction.

Therefore, future studies can consider the following aspects:

1) Fully considering the influencing factors of carbon emission reduction, the research will combine the low-carbon policy, market and technology to build a systematic alternative path for carbon emission reduction.

2) Emphasis should be paid to the important role of the financial system in the design and evaluation of carbon emission reduction paths. On the basis of giving full play to the functions of financing and risk sharing, the research on green financial service tools such as climate investment and financing, option regulation, and energy transformation fund should be strengthened, so as to smooth the capital channels for carbon emission reduction.

3) In the context of the global emission reduction targets, the realization of the dual-carbon targets also depends on the formation of a global unified carbon measurement standards. In the future, scholars will continue to pay more attention to the implementation effect of emission reduction, which

will promote the in-depth intersection of this field with natural science and social science, and then produce more valuable scientific research results, and contribute to the global carbon emission reduction cause.

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