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Review Paper

A Systematic Review on the Evolution of Carbon Emission Forecasting

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Abstract

Carbon emissions are a primary driver of global warming, prompting increasing research efforts to forecast carbon emission trends and mitigate their environmental impact. However, a systematic understanding of the existing literature on carbon emission forecasting is lacking. This study aims to provide a comprehensive review of this research field to inform decision-making. Specifically, the study summarizes the literature on carbon emission forecasts from three perspectives. First, it analyzes the general characteristics of the literature. Second, it visualizes and examines research topics and trends over different periods. Third, it explores the foundational knowledge, research content, and contributions of the literature, integrating them into a coherent knowledge framework. The visualization results indicate that the topics of carbon emission forecast studies have shown continuity over the past three decades. Meanwhile, research emphases differ between developed and developing regions. Based on these findings, policy recommendations are proposed, including the enhancement of energy efficiency standards, macro-regulation constraints, fiscal and tax incentives, and the optimization of the energy-emission structure.

Keywords: carbon emission, bibliometric analysis, forecast methods, policy implication

Introduction

As industrialization deepens around the world and the global economy rapidly develops, environmental problems have been getting worse in recent years. According to the World Meteorological Organization's (WMO) State of the Global Climate 2021 report, atmospheric greenhouse gas (GHG) concentrations in the world hit a record high of 413.2 ppm in 2020. To alleviate the environmental pressure caused by carbon emissions (carbon dioxide emissions) [1], international conferences have been held among various countries and regions to guarantee effective multi-national cooperation and urge the participants to jointly accomplish the goal of reducing CO_2 (carbon dioxide) and other greenhouse gases, and achieve sustainable development of the global economy. According to the topics of conferences and the agreements signed, they have provided direction for the carbon emission forecast.

Forecasting carbon emissions facilitates scientific estimates of carbon emissions in the future, and provides data and references for decision-makers. An increasing number of scholars have conducted studies on carbon emission forecasts, and the existing studies are focused on aspects such as the selection of forecasting indicators, optimization of forecasting models, and policy

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recommendations on forecasting results. Based on the characteristics of historical carbon emission changes, identification, and screening of influencing factors, and comprehensive analysis of forecasting methods can provide a scientific basis for finding the direction of formulating targeted low-carbon development routes. Moreover, carbon emission forecasting review is an important cornerstone for understanding the current status and exploring carbon reduction paths, and the choice of forecasting methods may indirectly affect the reliability of low-carbon decision-making results.

With the development of the field of carbon emission forecasting, many scholars have attempted to review carbon emission research in recent years. Such as Pedreira et al. (2022) reviewed 20 papers on carbon emission forecasts in Brazil, described the advantages and limitations of eight forecast models, compared the prediction accuracies shown in the results, and identified the most directly relevant forecasting indicators for carbon emissions [2]. They identified the economic structure as the most directly relevant factor of carbon emissions and made policy recommendations. Wang et al. (2019) analyzed 108 studies and inferred, according to the forecasting results of the studies, that China's industrial carbon emissions may peak by 2030 and that the reduction of energy intensity is the main cause of the decline in industrial carbon emissions [3]. Cai et al. (2021) explored the spatial modeling of carbon emissions in China [4]. They analyzed 125 journal articles in this field and discussed new techniques for spatial distribution and the applicability of forecasting methods. Hu et al. (2023) summarized recent research on energy consumption and carbon emissions forecasting in industrial processes, categorizing carbon emissions forecasting models into three types [5]. Jin et al. (2024) systematically reviewed 147 studies on carbon emission prediction models, comparing the accuracy of various models [6]. The above-mentioned literature provides a review of some aspects of the field of carbon emission forecasting, but most of these reviews use qualitative methods and lack a comprehensive and systematic review of the field using quantitative methods. In addition, few studies have summarized the trends of publication, forecasting methods, the content of forecasts, forecasting indicators, innovative conclusions, and policy implications in a systematic and comprehensive manner.

To fill the above research gaps, we used an array of methods, including scientific collaboration network analysis, literature co-citation analysis, cluster analysis, and co-word analysis. Specifically, we analyzed 2,775 articles on the WoS dataset published between 1990 and 2021 to investigate the characteristics of studies on carbon emission forecasts, explore their knowledge bases, and identify the evolution of key research topics. The results reveal the status quo, hotspots, key trends, the features and connections of knowledge structure, potential directions, practical significance, and policy implication of the research in this field. To achieve the above research objectives, we aim to answer the following research questions: (1) What is the current status of research on carbon emission forecasts? (2) What are the topics discussed in studies on carbon emission forecasts over the past 30 years? (3) According to the comparison of research topics in the field of carbon emissions forecast during different periods. How have the topics evolved? (4) What are the future directions of research on carbon emission forecasts? (5) What countermeasures or policy recommendations can be made from the results of the carbon emission forecast review?

In this study, we first elaborate on the background knowledge of carbon emissions and clarify the scope of the literature search. Analyze the general characteristics, knowledge graphs, and research themes of the carbon emission forecast literature obtained from the Web of Science (WoS) database. Analyze the research content, research methods, and development trends of carbon emission forecast literature. The purpose of this bibliometric and literature analysis is to provide scholars in this field with a basic knowledge framework on the methodology and content of carbon emission forecasting and to provide policy recommendations from governments, enterprises, and research institutes based on the research results.

Background Basics of Carbon Emission Forecast

Carbon Emission Concepts

The trace components of the atmosphere that cause the greenhouse effect are called greenhouse gases (GHGs). As specified in the Kyoto Protocol, there are six greenhouse gases, including carbon dioxide (CO_2), methane (CH4), nitrous oxide (N2O), and fluorinated gases (e.g., hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride). In terms of the contribution to global warming, CO_2 takes a large proportion (about 25%) due to its large amount. Therefore, it is the major greenhouse gas that is widely studied. The main cause of global warming is the excessively rapid rise of CO_2 concentration in the atmosphere due to the overuse of energy and overexploitation of natural resources by human beings during their development. Due to the large amounts of emissions and the wide influence of CO_2, "carbon emission" was the focus of the literature retrieval conducted in this study.

Carbon Emission Forecast Literature

IPCC reports show that carbon emissions can be divided into direct and indirect emissions. This study mainly focuses on direct carbon emissions. Indirect emissions were expressed as "embodied carbon (or CO_2) emissions" in the literature search, as a way of covering studies related to carbon emissions as completely as possible.

Materials and Methods

The analysis by bibliometric software generally consists of three steps: data collection, screening, and knowledge graph plotting [7], which will be detailed in the subsequent sections.

Search Strategy and Data Collection

This study completed data collection by selecting studies from the WoS. The database is produced by Thomson Reuters and has become one of the world's leading bibliographic and literature sources. It provides users with online access to a range of resources and classifies the resources into different citation groups. WoS has been widely used in bibliometric studies, and most of the studies involved are interdisciplinary or at the intersection of natural and social sciences. Therefore, the WoS was used for literature identification and collection in this study.

According to the concepts related to carbon emissions discussed in Section Background Basics of Carbon Emission Forecast, this study regarded carbon as the main gas contributing to carbon emissions in its literature retrieval. In this study, the distinction between the two was not underscored in the data collection step, with "carbon emission" used as the keyword for the search. Whether the studies on "forecasts of natural carbon" should be excluded was discussed in the data screening step. To explore the initial literature on carbon emission forecast, this study did not set the time of the literature before the search, and the optimal results were obtained based on the experience of related literature reviews and practice. Afterward, this study set the keywords for the search as "carbon emission(s) forecast" OR "carbon emission(s) predict" OR "carbon emit forecast" OR "carbon emit predict" OR "CO_2 emission(s) forecast" OR "CO_2 emission(s) predict" OR "CO_2 emit forecast" OR "CO_2 emit predict" OR "carbon dioxide emission(s) forecast" OR "carbon dioxide emission(s) predict" OR "carbon dioxide emits forecast" OR "carbon dioxide emits predict" OR "carbon footprint forecast" OR "carbon footprint predict" OR "greenhouse gas emissions forecast" OR "greenhouse gas emissions predict" OR "GHG emissions forecast" OR "GHG emissions predict", and selected Science Citation Index Expanded and Social Sciences Citation Index in the WoS as the sources. As a result, 4450 documents were obtained.

Data Filtration

As the WoS database covers a wide range of disciplines and research directions, the same search terms may lead to studies in different fields, which may hinder the readability and accuracy of the visualization results of the software. Although "Removing Duplicates", a built-in tool from CiteSpace, can help remove duplicates, practice shows that there are still many irrelevant articles in the analysis results. Therefore, prior to the visualization and review of the literature, this study screened the literature before inputting it into the software in order to ensure that the data input into the visualization software is pure and does not contain too much irrelevant information and make the results more readable and relevant to the topic. 3,689 papers were obtained after the boxes "English only" and "papers only" were ticked.

According to the search results and the principles of manual screening, the 3,689 valid papers were manually read and screened. The authors carefully read the titles, abstracts, and keywords of the 3,689 results and first excluded those that did not contain the search terms in any of the three parts. Secondly, they determined whether the studies should be removed based on whether their abstracts were in line with the searched topics. When no judgment could be made according to the title, abstract, and keywords, the two authors read the whole article to determine whether it belongs to the scope of carbon emission forecasting. The authors analyzed the research questions and objectives and only retained those focused on the environment and management. If the authors still could not make a judgment on a specific article, they classified it as an input item according to the principles of CiteSpace. The whole screening process is shown in Fig. 1. After all these steps, 1,154 valid papers were obtained, which were entered into CiteSpace for analysis.

Domain Visualization

The visualization part of this study consists of citation analysis, co-citation analysis, keyword co-occurrence mapping, timelines of clusters, and time-zone co-occurrence mapping. The analysis framework of data input and output is shown in Fig. 2.

Research Cooperation Network Analysis

Scientific collaboration network analysis is a method to describe the interpersonal network of researchers. The nodes of such a network can be researchers, research institutions, and regional or national research entities. If two entities perform research activities together, an edge would be created between the two nodes. Nodes and edges form a network. Like most complex networks, scientific collaboration networks have characteristics such as complex network statistics, complex dynamic node behavior, sparse network connections, complex connection structures, and complex spatial-temporal network evolution. In this study, we mainly analyzed institutional collaboration and co-authoring.

Co-Citation Analysis of the Literature

Co-citation refers to one or more papers citing two or more papers at the same time, and there is a co-citation relationship between the two papers. Frequent

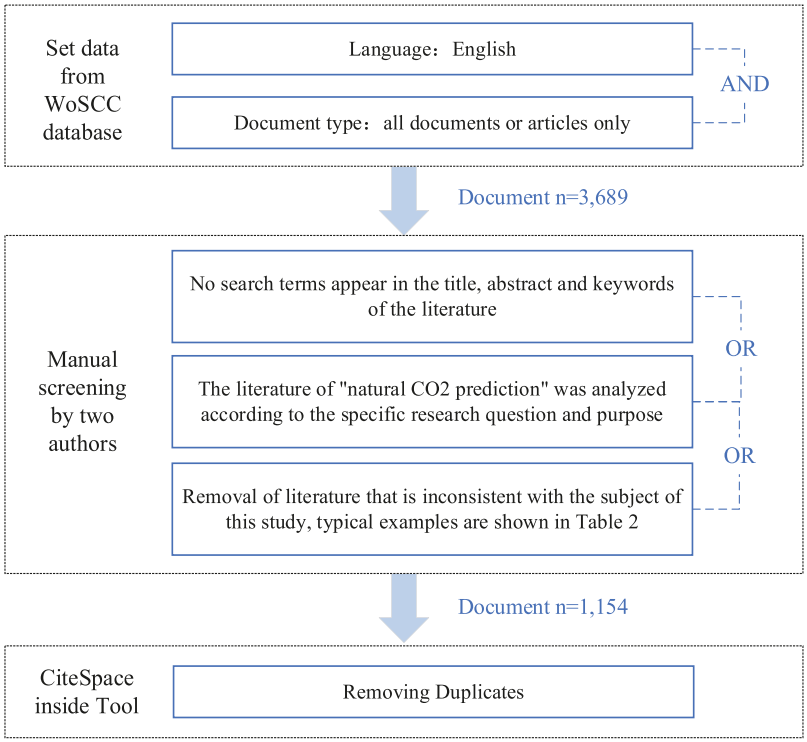

Fig. 1. Data filtration steps.

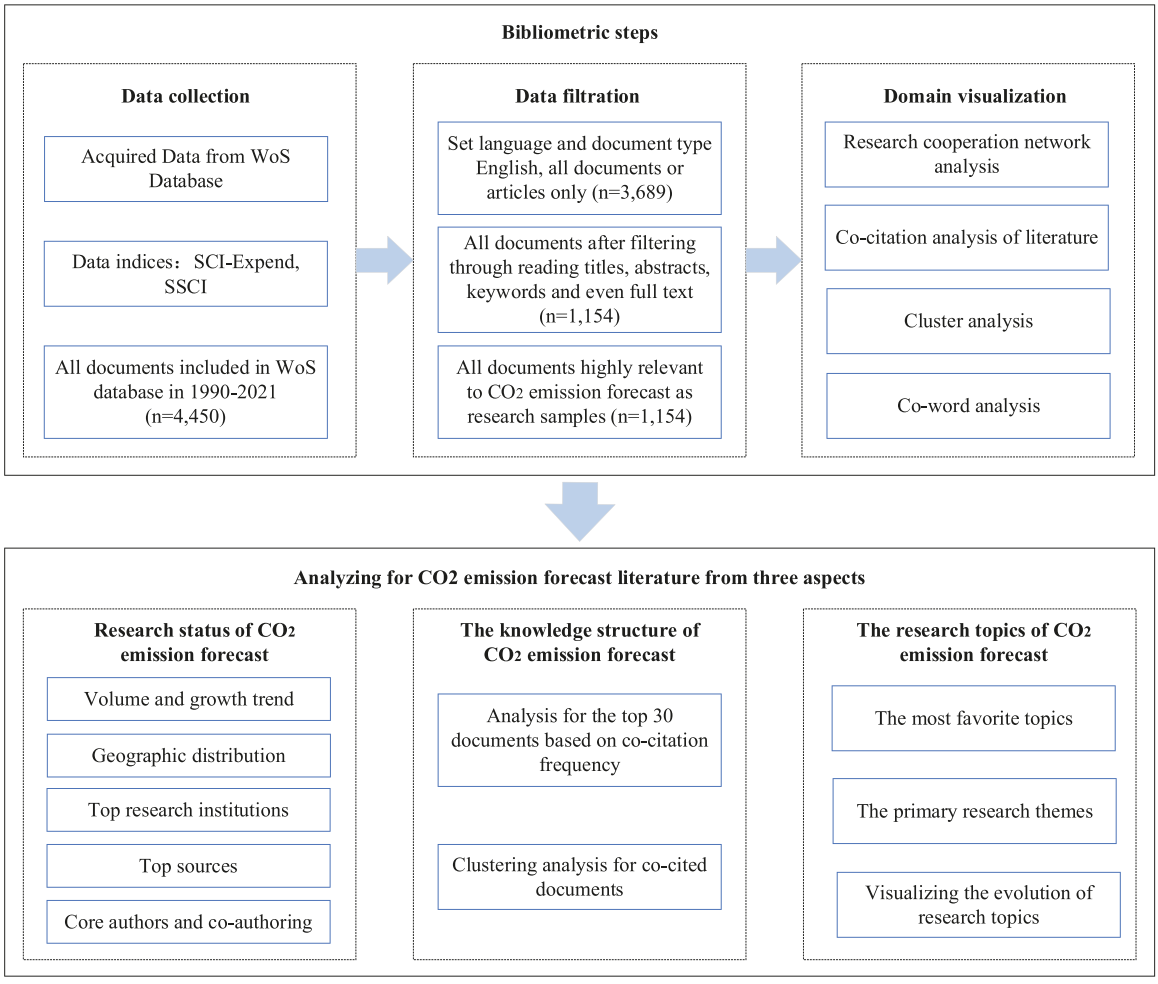

Fig. 2. Bibliometric visualization steps and analysis framework.

co-citations of studies indicate that they share a relevant research topic. Co-citation analysis of literature is a research method introduced by. Co-citation analysis has a broad and measurable impact on information science and on external fields. Scholars use it as a tool to map disciplines or specialties. Co-citation analysis of literature can help obtain a knowledge base for the research topics from an ocean of literature data. In this study, the knowledge base of the research on carbon emission forecast is systematically summarized through literature co-citation analysis.

Cluster Analysis

Cluster analysis is a widely used bibliometric and visualization method in data mining. Some keywords with high co-occurrence intensity form a cluster. There are many types of clustering algorithms, such as hierarchical clustering, non-hierarchical clustering, K-means clustering, and intelligent clustering. This study mainly used clustering based on the co-citation of literature and keywords.

Co-Word Analysis

Co-word analysis, as a method for content analysis, is a typical co-occurrence analysis method. It is used to analyze the relationship and intensity of the co-occurrence of word pairs in an article, reflecting the relationship between words and revealing the internal structure and changing trends of a specific research field. Co-word analysis was first proposed by Callon et al. in the 1980s. It has been widely applied in fields such as scientometrics and information. The most important feature of the co-word analysis is that words are used to represent the main content of papers. The relationships and strengths between co-words are analyzed to reveal the hotspots, frontiers, and development trends of the research field. This study adopted the co-word analysis method for keywords.

Visualization Tools

Software programs such as CiteSpace, HistCite, BibExcel, VOSviewer, and Ucinet are currently commonly used for bibliometric analysis. This study used CiteSpace for the quantitative study of the literature on carbon emission forecast. CiteSpace is easy to use and can help analyze the trends and patterns in the literature. It is a stepwise visualization tool for the knowledge domain. Based on the theory of co-citation analysis and pathfinder network algorithms, it helps explore the critical paths of the evolution of research topics and turning points in the knowledge domain and presents the results of the bibliometric analysis as a series of visual knowledge graphs, with the time-varying dual characteristics between the knowledge base and the research frontier illustrated in details. Therefore, CiteSpace can not only plot the scientific knowledge graphs of literature information on carbon emission forecast through citation analysis, co-citation analysis, and keyword co-occurrence but also interpret the knowledge graphs through timelines of clusters, time-zone and co-occurrence maps, and the analysis of word frequency, betweenness centrality, and burst terms.

The HistCite software was used for the supplementary analysis of aspects such as the number of citations. HistCite is a software package for the visualization of the time of citations. This program involves an important parameter metric, the Global Citation Score (GCS), which represents how many times a specific paper is cited by various types of studies in the WoS database. The combined use of both visualization software programs can increase the accuracy of quantitative studies of the literature.

Results and Discussion

General Characteristics of Carbon Emission Forecast Literature

Volume and Growth Trend of Carbon Emission Forecast Literature

We accounted for 1,157 carbon emission forecast literature documents from the WoS. From the bar chart of Fig. 3, the number of carbon emission forecast literature has increased from 1990 (1 publication) to 2021 (215 publications). From the growth rate line graph of Fig. 3, the growth rate is relatively slow and fluctuating, occurring from 1990 to 2009, but after 2009, the growth rate accelerates, especially from 2015 (46) to 2021 (215), and reaches its peak in 2021. Given the changing trend of the number of documents and actual background, we divided the evolution process of carbon emission forecast literature into two stages. We named the first nineteen years (1990 - 2009) the exploration stage and the second six years (2010 - 2021) the expansion stage.

Based on the exponential fitting trend line ($R2=0.9744$), it is expected that the number of documents related to the carbon emission forecast document will increase steadily from 2021 to 2024. Meanwhile, given the recovery of the global pandemic, the resumption of work in various industries, the return of climate issues in the public eye, and the promulgation of national/regional policies and carbon emission development targets. As a result, a new increase in the number of carbon emission forecast studies is expected.

Geographic Distribution of Carbon Emission Forecast Literature

The dataset shows that a total of 1,152 research papers on carbon emission forecasting have been contributed by various countries or regions. Only 2 of the total 1,154 publications do not contain information

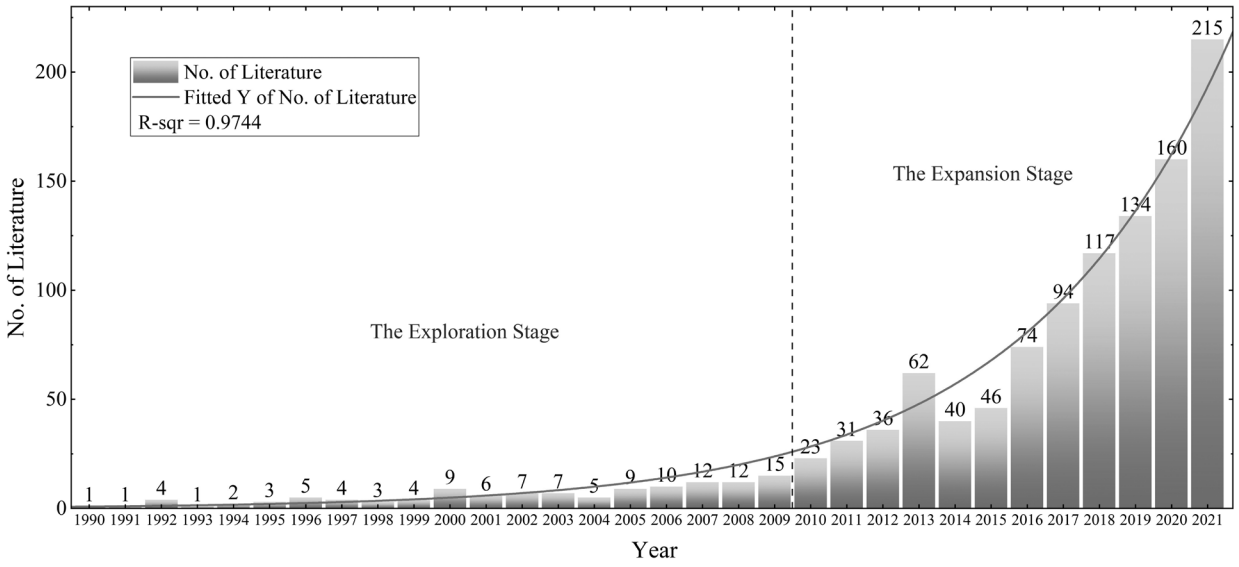

Fig. 3. Number of publications related to CO_2 emission forecast by year from 1990 to 2021.

on the country or region of the first author. Among them, China (463, 40.122%) and The United States (207, 17.938%) are the two countries that published the most papers on CO_2 emission forecast, followed by The United Kingdom (113, 9.792%), Canada (67, 5.806%), and Turkey (60, 5.199%), as shown in Fig. 4. Therefore, it can be tentatively determined that carbon emission forecast research has good development prospects, and the carbon emission forecast research output is positively correlated with the economic level, emission reduction technology level, emission reduction willingness, and emission reduction target accomplishment of most of the mentioned countries or regions.

Top Research Institutions in Carbon Emission Forecast Literature

The most significant number of publications come from the North China Electric Power University (64, 5.546%), followed by the Chinese Academy of Science (31, 2.686%), and Tsinghua University (27, 2.340%). In terms of citations, the total local citation score (TLC) refers to the number of citations in these 1,154 publications; the most TLC institutions are North China Electric Power University (169), and National Chiao Tung University (129). Total global citations score (TGCs) refers to the total number of citations to the literature, with the most cited being Tsinghua University (1301), and North China Electric Power University (1214).

The research institutes of carbon emission forecast research have formed a key collaborative network with an institutional hub. The most diverse partner institution is the Chinese Academy of Sciences, with a network of partners involving the University of Chinese Academy of Sciences, European Univ Lefke, Shenzhen University, and Beijing Normal University. Another emerging center for institutional cooperation networks is Tsinghua University, with its network of partners involving Xian Jiaotong University, the University of California, Berkeley, the University of Michigan, and the Beijing Institute of Technology. The Institute of Technology. In addition, it contains information on the collaboration between institutions that began 20 years ago, as shown in Fig. 5.

Top Sources in Carbon Emission Forecast Literature

The analysis of the 1,154 papers by the analysis tool that comes with WoS and HistCite reveals that these are from 312 journals. Among these, the Journal of Cleaner Production (102, 8.839%) was the most important publication. This was followed by the Energy Policy (77, 6.672%) and Sustainability (65, 5.633%). The top 20 sources contributed 665 CO_2 emission forecast papers, accounting for 57.626% of the 1154 papers. In terms of the number of total local citation sources, the Journal of Cleaner Production (312) is the most cited, followed by Energy (274) and Energy Policy (149). The top 20 TLCS ranked a total of 1,148, representing 81.48% of the All-TLCS for the carbon emission forecast research. In terms of source quality, the quality of the top 20 journals is relatively high overall, with impact factor scores ranging from 1.871 to 13.716.

In terms of source categories, most of the top sources publishing carbon emission forecast literature are dominated by energy and environment journals, with a small number of journals related to energy economics, energy policy, or industries with high carbon emissions due to the positioning of this study for carbon emission forecasting. This clearly demonstrates the diverse and interdisciplinary nature of carbon emission forecast research.

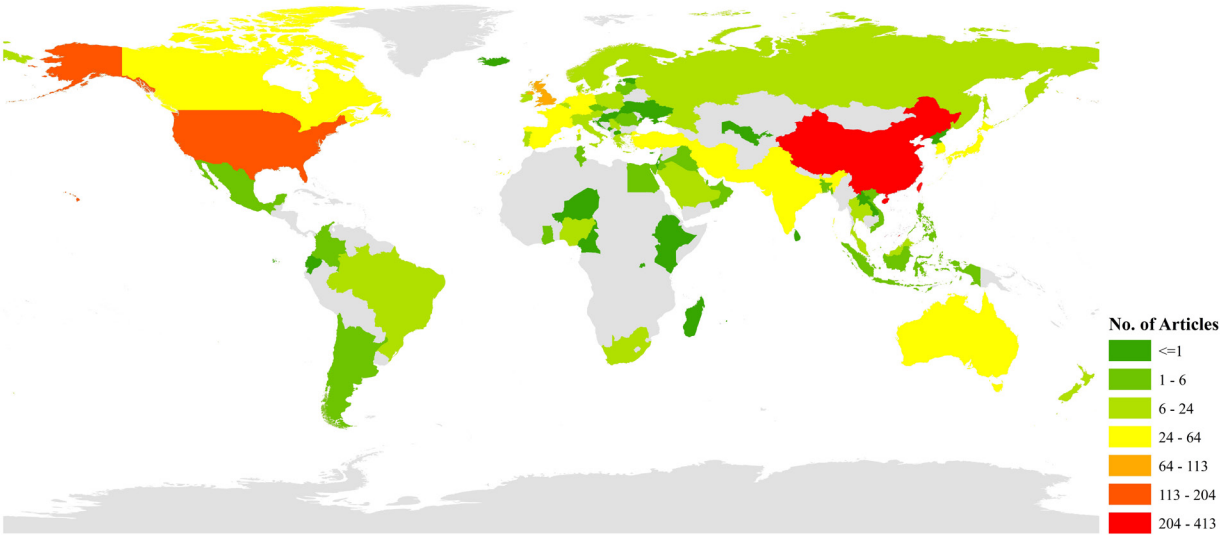

Fig. 4. Geographical distribution of CO_2 emission forecast publications across different countries between 1990 and 2021.

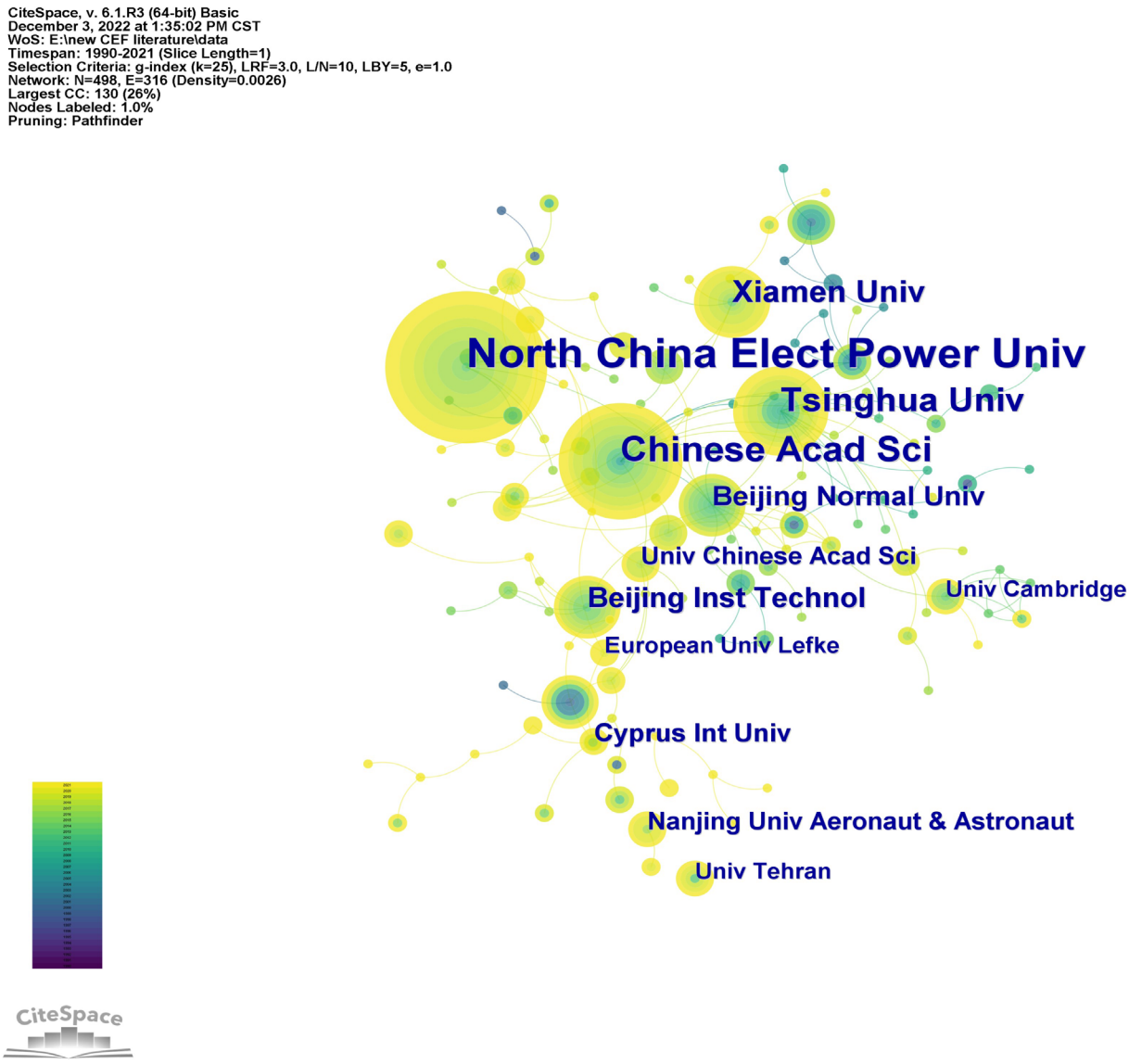

Fig. 5. Research institution's cooperative network of CO_2 emission forecast research between 1990 and 2021.

Core Authors and Co-Authors in Carbon Emission Forecast Literature

Analysis of these 1,154 papers by HistCite reveals that a total of 3,565 authors were involved in carbon emission forecast research from 1990 to 2021. Calculated according to Price's law, $m = 0.749\sqrt{n_{\max}}$ (m) represents the lower limit of the number of articles of core authors and $\sqrt{n_{\max}}$ represents the number of publications of the most prolific authors), which determines the core author group. After counting the number of publications, Lin has published 11 articles, so m=2.484. Therefore, authors with three or more papers are the core authors in carbon emission forecast research. Our analysis shows that 150 core authors have 581 publications in carbon emission forecast research, accounting for 50.35% of 1,154 documents, slightly exceeding the 50% standard of Price's law. In terms of total citations, the publications by 150 authors accounted for 51.61% of the total sources of all publications. It is shown that carbon emission forecast research has experienced 32 years of development, and a stable core group of authors has been formed.

The extent to which authors influence research topics is measured by their total number of publications and citations and the number of articles in which they collaborate with other authors [8]. As evident in Fig. 6, co-authors of carbon emission forecast research were divided into different clusters. It is observed that authors with many publications show prominent network characteristics, indicating that several research teams with higher output have been formed in carbon emission forecast research. Among them, Kirikkaleli, Adebayo, and Lin, at the core of the research team, had more representatives. The team of Kirikkaleli and Adebayo focuses on the relationship between regional carbon emissions and the economy. Lin's team focuses its research on forecasting carbon emissions and reduction potential in industries.

Knowledge Bases of Carbon Emission Forecast Literature

Analysis of the Top Twenty Documents Based on Co-Citation Frequency

The frequency of co-citations of studies reflects the leading results in the development of carbon emission forecast research, which has a great influence on the previous and even future research in the field. Based on the guidance of [9], this study selected 20 co-cited articles with great influence, among which a paper by Sun published in 2016 is the most cited (39). These top 20 most cited papers were selected to dig deeper into the key knowledge base of the research area of carbon emission forecast. An in-depth understanding of the content and contributions of these landmark studies enables a deeper understanding of the current situation of research in this field. The Top 20 research topics were obtained through the review and analysis of the co-cited studies, which roughly fall into two categories: studies focused on forecasts and studies focused on the identification of influencing factors and supplemented by forecasts. The relationship is shown in Fig. 7.

Clustering Analysis for Co-Cited Documents

In general, the quality of clustering is determined by two basic values. One is the Q value of the clustering module. When Q>0.3, the clustering result is significant. The other is expressed by the weighted average silhouette coefficient (S). When S>0.5, the clustering effect is good, and when S>0.7, the clustering effect is reliable. As shown in Fig. 8, in this study, Q=0.94 and S=0.8862, suggesting the clustering effects of co-cited studies on carbon emission forecast. The clustering results and the structure chart show that the literature on carbon emission forecasts from 1990 to 2021 consists of 59 clusters. As the existence of some clusters is not significant, only the top-ranked clusters in terms of size and silhouette were studied and analyzed in this study. The main clusters were #0 carbon emission forecasting, #1 influencing factors, #2 peak, #3 economic growth, #4 energy economics, #5 multiple equilibria, #6 environment management, #7 life cycle, #8 hybrid model, #9 atmosphere, #10 scenario analysis, #11 sensitivity analysis, #12 Kyoto protocol, #13 energy efficiency, and #14 transmission. This result reveals that although the research on carbon emission forecasts has been developed for more than three decades, the research in this area is still booming.

Research Topics of Carbon Emission Forecast Literature

The Most Favorite Topics in Carbon Emission Forecast Literature

Keywords are the essence of an article and a powerful summary of the topic and content of the article. The more frequently a keyword appears, the more popular the topic it represents. As seen in Table 1, from the perspective of keyword frequency, in the exploration stage, the keywords with the highest frequency are "CO_2 emission", followed by "climate change", "greenhouse gas emission", and "model". In the expansion stage, the most frequent keywords are "CO_2 emission", followed by "energy consumption", "economic growth", and "greenhouse gas emission".

In addition, the greater the centrality of a keyword, the more prominent the topic it represents in the keyword co-occurrence network. A centrality greater than 0.1 is generally considered influential. In terms of the centrality of keywords in studies on carbon emission forecast, "CO_2 emission" is the keyword with the strongest centrality in both stages. Besides, 9 keywords ("CO_2 emission", "climate change", "greenhouse gas emission", "model", "economic growth", "energy

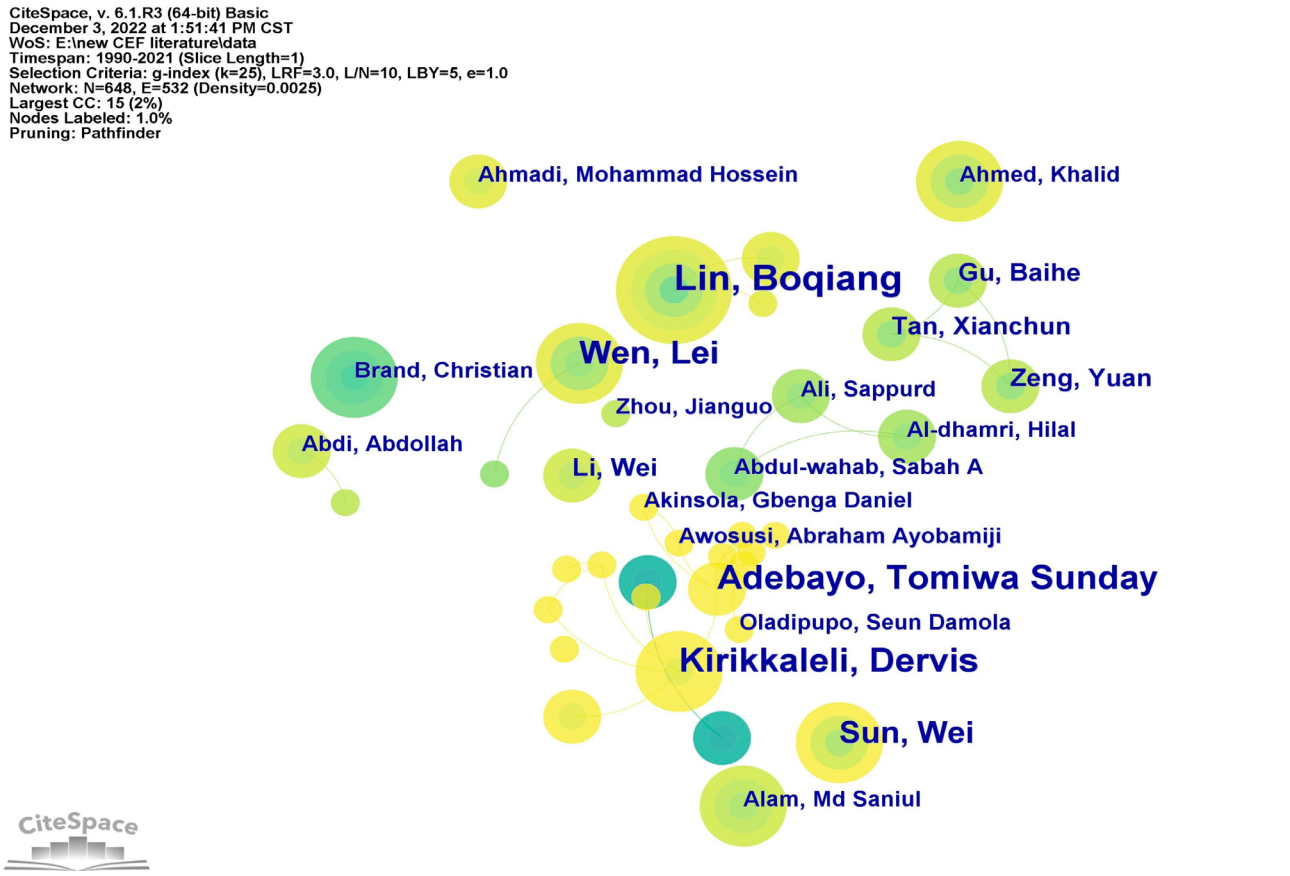

Fig. 6. Author collaboration network of CO_2 emission forecast research between 1990 and 2021.

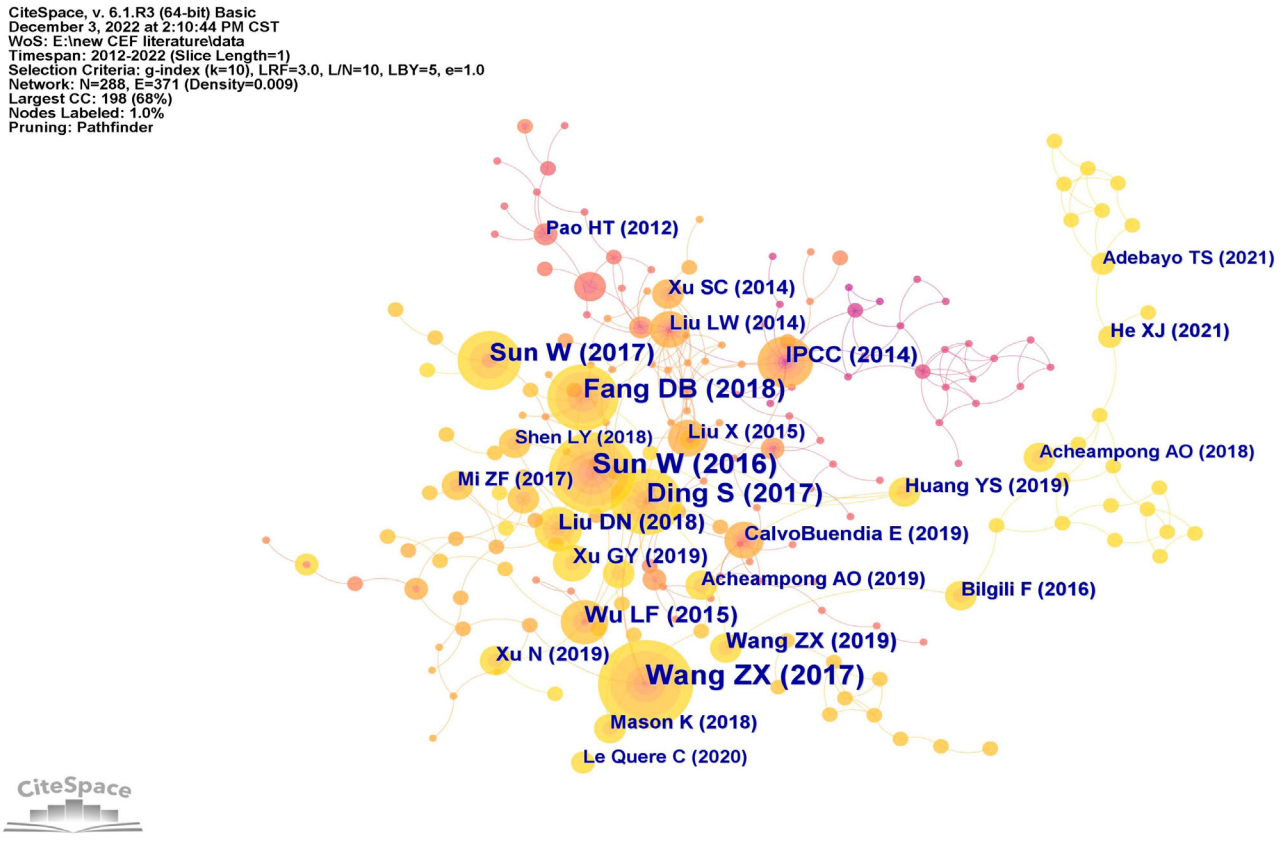

Fig. 7. Literature co-citation network of CO_2 emission forecast research between 1990 and 2021.

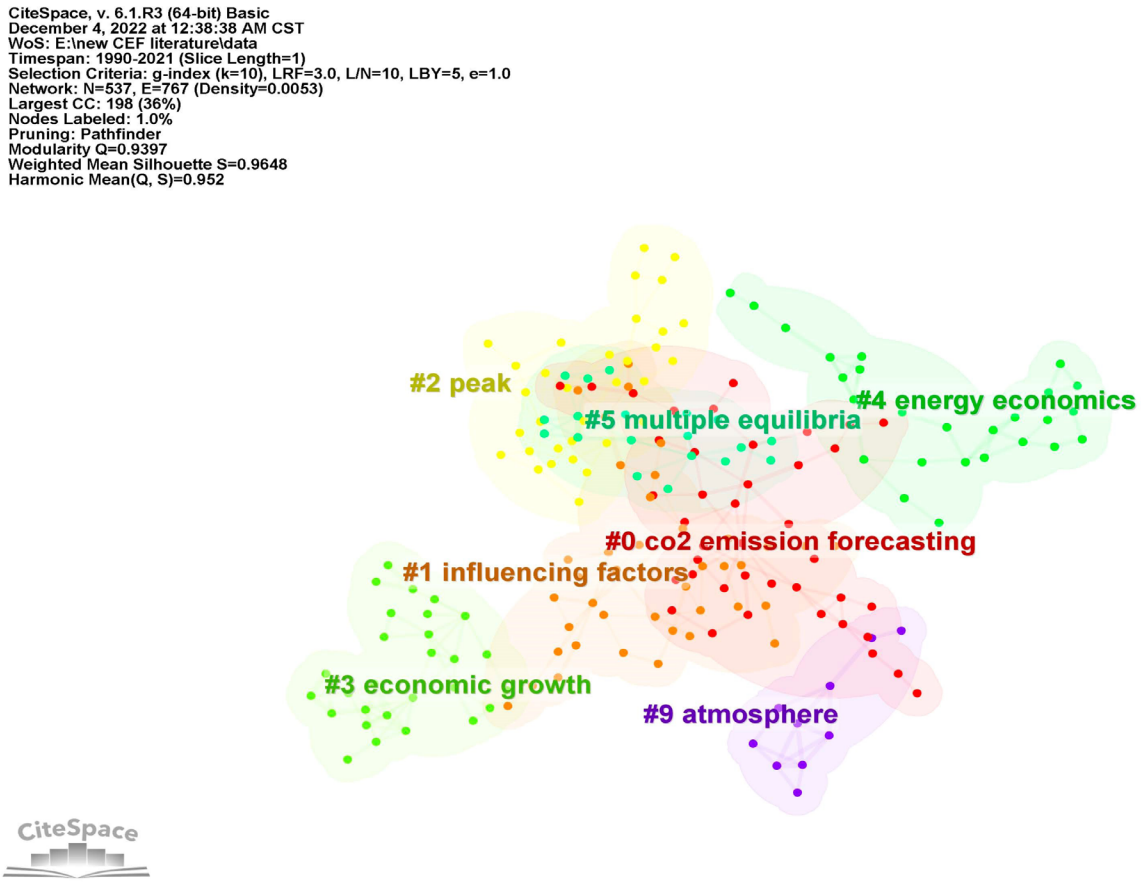

Fig. 8. Clustering for co-cited documents of CO_2 emission forecast research between 1990 and 2021.

consumption", "environmental Kuznets curve", "energy demand", "policy") appear in both stages, and the rest of the keywords are also semantically similar, indicating that not much new content has been added to the top 20 research hotspots in the literature on carbon emission forecast from 2009 to 2021. "CO_2 emission", "greenhouse gas emission", and "carbon emission" appeared for the first time in 1992, 1996, and 2000, respectively.

The Primary Research Themes in Carbon Emission Forecast Literature

We chose the LLR algorithm in CiteSpace software, which is more suitable for generating high-quality clustering with intra-class similarity and inter-class similarity to cluster keywords. Similar to the analysis of keywords, the literature on carbon emission forecast was divided into two stages for the thematic clustering study. The K method and LLR were selected to study the literature in both phases by keywords. The clustering results were obtained by CiteSpace: QA=0.8288, SA=0.9445, QB=0.7761, SB=0.891 (Q>0.3 and S>0.5 in both stages), indicating that the clustering results are credible. In the exploration stage, studies are mainly focused on climate and environmental protection, while in the expansion stage, studies are mainly expressed as #energy management and #economic growth, respectively. It is worth noting that studies on #CO_2 emissions and #carbon emissions across various levels became the key research topics in the two stages. In the subsequent two stages, CO_2 emission became synonymous with CO_2 emission after the adoption of the Kyoto Protocol.

The function of CiteSpace was used to label the 11 clusters of the two stages as A0-A10 and B0-B10, and the size, silhouette value, year, and top term in LLR were calculated, as shown in Table 2.

Visualizing the Evolution of Topics in Carbon Emission Forecast Literature

The key point of the timeline analysis of keywords is to reveal the relationship between clustering and the historical span of the keyword collection [10]. Similarly, the timeline analysis of the literature is conducted in two stages to investigate the key points on the timeline of carbon emission forecast research. Specifically, in stage 1, #1 CO_2 emission appears at the earliest time node and the largest node, so the literature on the research topic of carbon emission forecast emerged around 1990. According to stage 2, the total number of current studies on carbon emission forecasts grows rapidly, still focused on the topics discussed in 2010 or even earlier.

Table 1. Frequency and Centrality of the Top Ten Keywords of CO_2 Emission Forecast Research.

No.	The Exploration Stage 1990~2009				The Expansion Stage 2010~2021			
	Keywords	Freq	Cent	Year	Keywords	Freq	Cent	Year
1	CO_2 emission	44	0.43	1990	CO_2 emission	621	0.03	2010
2	climate change	18	0.27	1992	energy consumption	380	0.01	2011
3	greenhouse gas emission	17	0.20	1996	economic growth	225	0.08	2010
4	model	9	0.67	1992	greenhouse gas emission	216	0.04	2010
5	economic growth	9	0.19	1999	energy demand	166	0.06	2010
6	energy consumption	9	0.25	2000	environmental impact	159	0.04	2011
7	impact	7	0.05	2000	model	143	0.06	2010
8	developing country	5	0.10	1997	china	116	0.14	2011
9	energy	5	0.29	1995	scenario analysis	104	0.06	2010
10	environmental kuznets curve	5	0.05	1999	climate change	102	0.03	2010

Table 2. Frequency and Centrality of the Top Ten Keywords of CO_2 Emission Forecast Research.

ID	Cluster	Size	Value	Year	Top Term in LLR
A0	model	42	0.876	2003	model; global warming; atmosphere; greenhouse gases
A1	CO_2 emission	29	0.983	2002	CO_2 emission; carbon dioxide; simulation; hydrogen
A2	environmental kuznets curve	22	0.898	2004	environmental kuznets curve; offsite benefits; CO_2-projections; carbon permit price
A3	multiple linear regression	22	0.971	2000	multiple linear regression; land use change emissions; CO_2; NO_2; steelworks process modelling
A4	life cycle assessment	21	0.910	1994	life cycle assessment; carbon dioxide emissions abatement; biodiesel; environmental tax
A5	community	20	1.000	2005	community; beef cattle; Australian savanna; litter
A6	renewables	18	0.994	2002	renewables; carbon tax; greenhouse gas emission
A7	policy	17	0.940	2000	policy; energy; conservation; non-stationary panel
A8	carbon balance system	15	0.974	1996	carbon balance system; validation; system; paddy; nitrous oxide
A9	energy consumption	10	0.958	2000	energy consumption; cook stoves; car ownership; particulate emissions; global warming commitment
A10	climate change	10	0.984	2003	climate change; emission of greenhouse gases
B0	CO_2 emission	32	0.846	2015	CO_2 emission; climate change; scenario analysis
B1	grey model	30	0.867	2017	grey model; particulate matter; land use change
B2	energy management	29	0.870	2015	energy management; energy saving; artificial neural networks; energy efficiency; material flow analysis
B3	extreme learning machine	27	0.898	2016	extreme learning machine; civil aviation; energy consumption structure; building construction phase
B4	economic growth	26	0.890	2017	economic growth; urbanization
B5	stirpat model	24	0.915	2015	stirpat model; emission scenarios; grey model
B6	artificial neural network	23	0.900	2015	artificial neural network; bp neural network; particle swarm optimization; impulse response
B7	scenario simulation	22	0.820	2012	scenario simulation; artificial intelligence; grey model
B8	emissions peak	21	0.882	2014	emissions peak; carbon tax; nuclear energy
B9	CO_2 emission mitigation	21	0.943	2016	CO_2 emission mitigation; climate mitigation; behavior; expert elicitation; carbon intensity
B10	influencing factors	21	0.869	2016	influencing factors; air pollution; global warming

Research Status of Carbon Emission Forecast Literature

Regarding Annual Publications and Trends in Carbon Emission Forecast Literature

This study utilized bibliometric tools to analyze literature on carbon emission forecasting, focusing on relevant papers identified from the WoS. The analysis revealed a significant exponential increase in publications from 1990 to 2021, with a notable surge in the past six years, which accounts for 68.8% of the total publications in this period. This rapid increase in recent years suggests a growing academic and practical interest in carbon emission forecasting, driven by heightened global awareness of climate change and policy development.

The literature trends indicate that the field of carbon emission forecasting is unlikely to plateau in the near future. This continued growth can be attributed to several factors: heightened international focus on emission reductions, frequent policy revisions, proactive corporate responses to emission targets, and ongoing advancements in emission reduction technologies. These factors collectively contribute to an accelerated development of carbon emission forecasting literature and the emergence of new research subcategories aligned with economic, technological, and policy changes.

As illustrated in Fig. 3, the initial phase of literature growth was slow; however, a marked increase occurred by 2010. Analyzing the publications from around 2010, alongside key climate conferences and agreements from that period, reveals several catalysts for this surge: (1) The initiation of the second phase of Kyoto Protocol development targets in 2011. (2) The release of the IPCC's third assessment report in 2013. (3) The expansion of research focus to cover a broader range of industries and directions. This pattern aligns with Price's law of increasing literature and reflects the growing societal and environmental emphasis on carbon emissions.

The growing attention to carbon emission forecasting underscores its critical role as a foundation for emission research. Researchers have developed various predictive methods and impact factor screening techniques, reflecting both the increasing academic interest and the practical need for advanced forecasting tools. This trend highlights the importance of continued investment in research to address the challenges and opportunities associated with carbon emissions.

Regarding the Distribution of Authors' Country/ Region for Carbon Emission Forecast Literature

In terms of the countries and regions in which carbon emission forecast research is conducted, the existing studies were mainly conducted in North America (the US and Canada), Europe (the UK, Spain, Germany, the Netherlands, Italy, Athens, Finland, etc.), and Asia (China, Japan, Korea, Iran, Malaysia, and Pakistan). The research directions and time nodes of published papers in each country or region have unique characteristics. Specifically, China and the US see the largest numbers of studies on carbon emission forecasts, and research in this field in China covers a wide range of sectors. Most studies predicted carbon emissions caused by fossil fuel combustion, construction materials, and transportation and explored the relationships between carbon emissions and the economy, technological development, and environment in the end. Studies on carbon emission forecasts conducted in the US are also diverse and largely related to energy and carbon markets. However, unlike in China, the correlation between the time of publication and policy is relatively weak in this research area in the US, which is related to the incoherence and instability of emission reduction targets of the US, but the research on carbon emissions has never stopped in the country. In European countries and Australia, most studies forecast carbon emissions by the building sector, the new energy sector, and animal husbandry. In addition, as countries in Northern Europe and Australia boast pastures, grasslands, and forests, many researchers have studied the carbon emissions from animal husbandry to explore pollution to the environment on the one hand and the relationship between carbon emissions and costs in the life cycle of animal husbandry on the other. Besides, countries such as the Netherlands have world-leading new energy technologies, such as wind power generation. Carbon emission forecasts can help indirectly assess the capacity of new energy sources and environmental governance in these countries and regions. In terms of Asia, some developed countries in East Asia and developing countries in Southeast Asia have also made contributions to carbon emission forecast research. All these examples show that carbon emissions have become an international concern that needs to be addressed urgently.

Regarding the Top Research Institutions that Publish Carbon Emission Forecast Literature

In terms of the top research institutions publishing carbon emission forecast research, key collaborative networks have been established among the institutions after more than three decades of development. However, due to the special nature of carbon emission forecast research, which involves multiple industries and is a complex interdisciplinary field, some of the collaborative networks among research institutions are not very close because of the limitations of research directions and categories. While this reasoning is valid, it does not delve deeply into the specific causes of this situation. Carbon emission forecast research involves various sectors and disciplines, which indeed leads to diversity in research directions and categories. However, whether this fully explains the lack of closeness in collaborative networks remains to be examined. Other potential factors, such as uneven distribution of

research resources, competition among institutions, or differences in policy and funding support, should also be considered. Among the top research institutions, those in China have lower centrality despite their high rankings in terms of the number of articles published and the proportion of the total, which means that carbon emission forecast research conducted by China's institutions is less influential in the world. Therefore, China's institutions should make more efforts to make their studies more in line with social development, strengthen the connections between research results and relevant studies, and achieve more innovative and applicable results.

Regarding the Top Research Sources that Publish Carbon Emission Forecast Literature

Regarding the journals in which studies on carbon emission forecasts have been published, 81.48% of the selected 1,154 were published in the Top 20 publications from 1990 to 2021. The Top 20 publications fall into the following ten fields: energy, environment, sustainability, economy, management, transportation, construction, electricity, policy, and agriculture. This demonstrates the interdisciplinary nature of carbon emission forecasting. However, different disciplines have varying standards, methodologies, and focuses, which could lead to inconsistencies in the research. Regarding the quality of the sources, the impact factors of the Top 20 journals are high, with JCR concentrated in Q1 and a few scattered in Q2. After the Top 20 journals in terms of the number of articles published and cited, there are also journals with moderate or weak quality among the next 300 journal sources. This indicates that carbon emission forecast research has received attention from both top and novice researchers and has become a widely studied topic.

Regarding the Core Authors Who Published Carbon Emission Forecast Literature

In terms of core authors of published studies on carbon emission forecast, a total of 3,565 authors were involved in the 1,154 studies (published from 1990 to 2021) on carbon emission forecast selected from WoS, and 150 core authors have contributed 50.35% of the results. This shows that the carbon emission forecast has been studied by a group of core authors who are experienced in this field. However, the concentration of contributions among a small group of core authors might indicate a lack of diversity in perspectives in the research outcomes. In addition, this study found that the earliest collaboration among researchers on carbon emission forecasts appeared 20 years ago. The two most prominent research teams are led by Kirikkaleli, and Lin's team is reported to be growing. This suggests that there is still plenty of room for the development of new members interested in carbon emission forecasting.

The Structure of Carbon Emission Forecast Literature

After 32 years of development, the field of carbon emission forecasting has been studied for a long time. Although it is still rapidly developing with iterations of objects and methods for forecasting, a complete knowledge framework has been formed, which covers various aspects of the literature in this field, such as research content (objects), research methods, research data, and contributions (theoretical contributions and practical significance). Specifically, the framework presents two different ways of classifying studies on carbon emission forecast: (i) according to the content of research; and (ii) according to forecasting methods (Fig. 9). On this basis, the widely discussed content and commonly used methods in these studies are analyzed and summarized, and the key achievements and contributions of these studies are illustrated, presenting a full picture of the current development and future trends of the research on carbon emission forecast for scholars and practitioners.

Research Object

The objects of carbon emission forecast research can be divided into two main categories: anthropogenic CO_2 emissions from various industries and natural CO_2 emissions from the production of natural or agricultural products. The selection of these two types of literature has been discussed in the Data filter section, and only studies focused on the environment are considered in both categories.

Industrial. Industrial production and use are the main factors resulting in carbon emissions. Industry can be subdivided into various sectors, and the analysis of carbon emissions from various sectors and the studies selected in this paper show that the following sectors are large carbon emitters: (i) Energy; (ii) Electricity; (iii) Construction; (iv) Transportation [11]. The analysis of the sectors involved in the studies selected suggests that, due to the interdisciplinary nature of the research on carbon emissions, multiple sectors, rather than only one, might be discussed in one study.

(i) Studies on carbon emissions forecasts in the energy sector are conducted from two major perspectives, namely fossil fuels and clean energy. Specifically, studies focused on clean energy account for 20.62%-38.47%, which is the largest proportion among the five listed sectors. This is because energy is the basis for the technological and economic development of industries [12]. In the studies on carbon emissions forecasts, the main models used to predict carbon emissions from energy can be divided into the elasticity of energy consumption methods, bottom-up energy system models, and top-down and bottom-up system optimization models.

(ii) The electric industry contributes to the largest proportion of global carbon emissions, among which

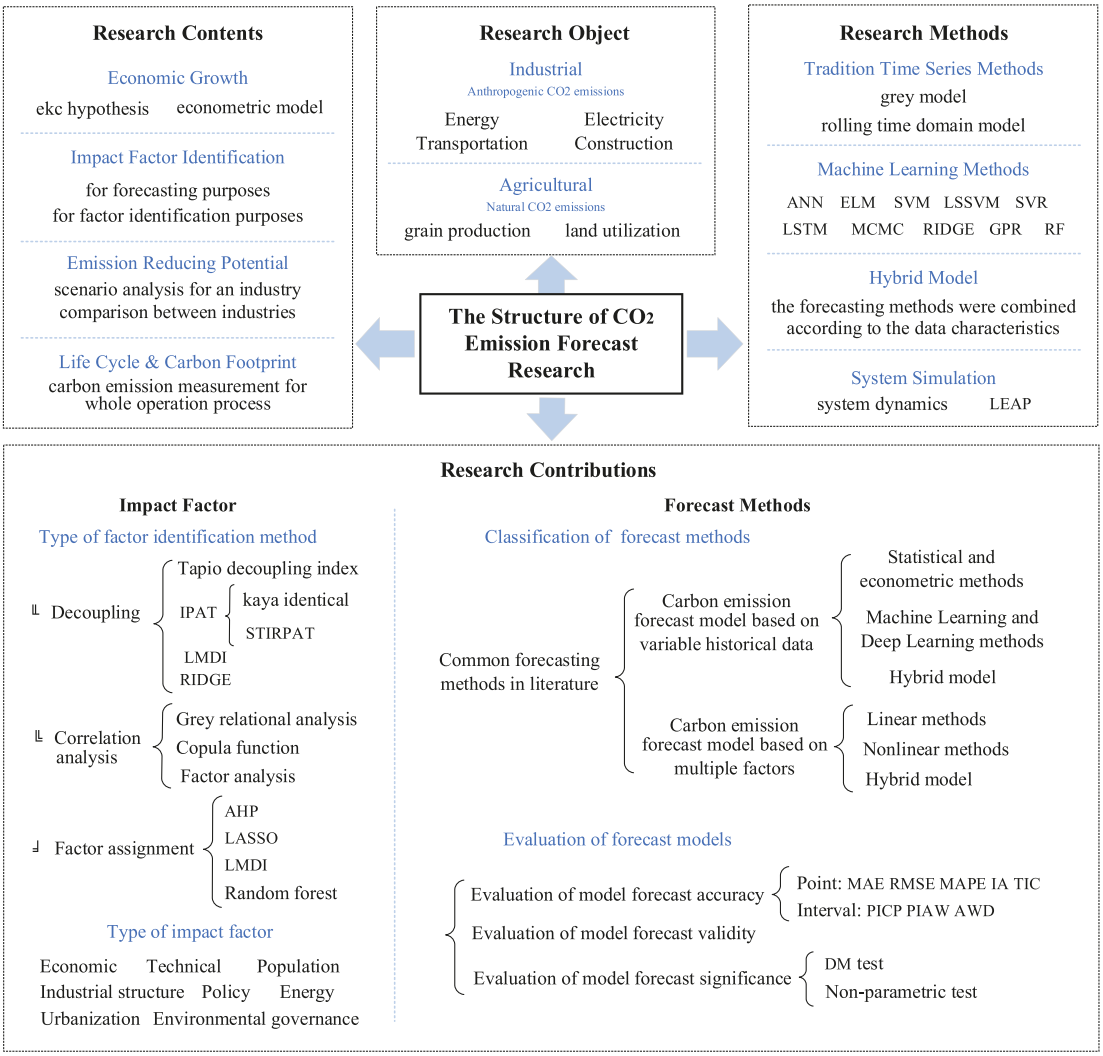

Fig. 9. The structure (research contents, research object, research methods, impact factor, forecast methods) of CO2 emission forecast literature.

electricity generation accounts for the largest share, and the demand for electricity will continue to grow in the future [13]. It is of vital significance to global emission reduction to accurately predict carbon emissions from the industry and the demand for electricity. “Electric” and “Energy” are often studied [14]. Likewise, top-down and bottom-up system optimization models are commonly used to predict demand and emissions [15].

(iii) Carbon emission forecasting in the construction sector is generally studied from two angles: low-carbon technologies and carbon emissions from building materials [16]; forecasting carbon emissions in different scenarios and designing low-carbon communities [17].

(iv) A large number of studies are focused on carbon emissions from the transportation sector, and projections are made based on emissions from delivery vehicles. The studies selected in this paper show that emissions from land transportation, private cars, urban transport networks [18], and aviation are commonly studied [19].

Agricultural products. Studies that predicted carbon emissions from agricultural products appeared relatively early, showing steady year-on-year increases in the number of studies. The relationship between the costs and carbon footprints of livestock farming, food production, and land use is the research focus [20]. Some scholars have simulated carbon emissions from the perspective of an ecological economy, and DNDC is a representative model [21].

Research Contents

Although carbon emission forecast has been a well-defined research topic, it can be seen from the retrieval and analysis of the related literature that studies in this field have different emphases, such as economic and technological growth impact, impact factor identification, multidisciplinary research, and life cycle and carbon footprint.

Economic growth. The relationship between economic growth and carbon emissions has become a major concern for various regions and industries, and forecasts of carbon emissions play a key role in

formulating international mitigation agreements and setting caps on emissions trading. According to IPCC reports, economic, technological, and population growth are the most important factors that drive up carbon emissions, and the contribution of economic growth has increased over the last decade. Most studies discussed the impact of economic and technological growth on carbon emissions based on the Econometric Kuznets Curve (EKC), explored whether the EKC hypothesis is valid, and predicted carbon emissions in different scenarios of development [22]. Some researchers used econometric models and simulation analysis to examine the cost-carbon emission system for specific industries, and CGE is a representative model [23].

Impact factor identification. The manual reviews reveal that most of the carbon emission forecasts in recent years have adopted the approach of identifying and screening the factors influencing carbon emissions, and some studies pay more attention to factor identification [24]. The selection of influencing factors is a key condition to ensure forecast accuracy, and it is also an important topic discussed in studies on carbon emission forecasts [25]. Widely used methods for decomposing and identifying influencing factors include LMDI [26], the Kaya Identity [27], and Random Forest [28].

Emission-reducing potential. Some studies on carbon emission forecasts reflect the emission reduction potential of a sector by examining carbon emissions over different periods. Sectors mentioned in the section on economic growth are the most studied. In particular, the amounts of emissions and emission reduction of electric power and the construction industry account for the largest proportions in the whole industry, and they have received the greatest attention [29].

Life cycle assessment and carbon footprint. Some studies on carbon emission forecast estimate the carbon emissions of the whole process of production of the research objects from the perspectives of life cycle and carbon footprint [30].

Research Methods

In addition to the selection and identification of influencing factors, the selection and improvement of forecasting methods is also an important way of ensuring the accuracy of carbon emission forecasting. According to the studies selected in this study, there are three major types of methods for emission forecasts, namely time-series approaches, machine learning methods, and hybrid models combining the first two. The outstanding contribution of carbon emission forecast research lies in the carbon emission impact factors in various industries/regions and the forecast methods applicable to the characteristics of carbon emission data.

Hot Topics and Theme Evolution of Carbon Emission Forecast Literature

This study reveals the keywords and the results of keyword clustering and timeline clustering for both stages of carbon emission forecast research. These keywords (e.g., carbon emission, model, climate change, energy, greenhouse gas emission, and impact) have been the hotspots of carbon emission forecast research for 32 years, which all belong to the top 20 keywords in both stages. Therefore, these keywords can be considered the traditional main lines and topics of carbon emission forecast research, which is the core of the research. At the same time, this also means that scholars may still further investigate these topics in subsequent studies.

This study has also found that the length and color of the timeline of a topic represent the future trend and popularity of the topic. The analysis results show that "economic growth with carbon emissions" will be a research hotspot and trend in the field of carbon emission forecast in the future. In the actual development of carbon emissions, the main context is "climate change", the main research content is "carbon emission", and the ultimate goals are "economic growth" and "climate policy". More importantly, "machine learning algorithms" and the latest technological methods can be used as new tools in carbon emission forecasting research. In addition, "trade opening" emphasizes the gradual emergence and improvement of carbon markets in various countries and regions, which means that there is another factor affecting carbon emission forecasting. These analyses provide some insights for future carbon emission forecast research. Some themes for carbon emission forecast research have continuity in the development from the exploration stage to the expansion stage. For example, B0, B2, B4, and B10 are essential themes of the expansion stage of carbon emission forecast research, and they inherit the tradition of the exploration stage of research topics A1, A9, and A10. For another, it is worth noting that the research methodology of carbon emission forecast research is also constantly changing. For example, the theme evolves from A5 in the first stage to B11 in the second stage; B1 is further developed based on A3, B3, and B6 have been deepened and expanded based on the research of A3. The revelation is that future research on carbon emission forecasts should inherit some traditional themes and pay attention to the evolution of themes. Therefore, future research must study conventional research topics and explore the application of new forecast methods in carbon emission forecast research.

The study shows that carbon emission forecast research has achieved good development in the past three decades. New forecasting methods and research directions have driven interdisciplinary development in the field.

Analysis of Future Research Directions

Based on literature co-citation and keyword co-occurrence, we believe that the future carbon emission forecast research mainly has two directions: expansion of research content and optimization of research methods.

Expansion of Research Content

Transforming the mode of economic development. The environment and economic development are some of the most important issues nowadays. Developing countries and regions need to change their economic development modes in order to realize sustainable development and achieve carbon peaking and carbon neutrality goals. Therefore, it is necessary to select methods that are built on the balance between economic development and the environment.

Emission reduction potential by region, industry, and enterprise. According to the above analysis, most studies on carbon emission forecasts start from the perspectives of industries or regions and explore the emission reduction potential based on the predicted future carbon emissions to pave the way for the subsequent studies on economic development, technological progress, and the allocation of carbon trading markets. However, only a few studies have been conducted from a micro perspective, at the enterprise level. In future research, the emission reduction potential of enterprises can be analyzed, and the economic and technical levels of enterprises to reduce emissions can be explored in the context of the general environment.

Consider the impact of carbon emissions trading and related policies on carbon emissions. According to the results of the bibliometric analysis, the relationship between carbon emissions and carbon emissions trading has not been sufficiently studied. The results of searching "carbon trading and related policies" in WoS show that the studies predicting carbon trading mostly forecast carbon prices. Carbon trading and related policies can reduce carbon emissions through three channels: technological innovation incentive mechanisms, production factor change mechanisms, and cost-benefit constraint mechanisms, which are significant for emission reduction. Therefore, in future research on carbon emission forecasts, the future carbon emission scenarios can be explored to reflect the effects of carbon trading and policies in emission reduction or the content of carbon trading-related policies can be selected according to the actual situation and used, as an influence index, for the subsequent forecasts.

Optimization of Research Methods

Impact factor identification methods. There are many factors influencing carbon emissions in various industries, and these factors are interacting with and intricately related to each other. How to identify the key factors and analyzing them from multiple perspectives is the basis of whether carbon emissions can be reduced to the target value and a key step to ensure the accuracy of carbon emissions forecasting. This study has found that the current methods for identifying carbon emission factors are mainly divided into two categories: mathematical statistics and machine learning.

Forecast methods. Through the above extensive literature analysis, forecasting approaches can be divided into time series forecasting and indicator selection forecasting, and forecasting methods can be divided into mathematical statistics and machine learning methods. According to the time of publication and the current methods, hybrid forecasting methods based on machine learning are the mainstream in the future. There are various forms of hybrid forecasting, such as the combination of the selection of influencing factors and forecasting methods, the optimization of the parameters of forecasting methods, and the cleaning and pre-processing of samples, all aiming to improve the accuracy of carbon emission forecasting.

Scenario and simulation. From the content of carbon emission forecast research, some studies discuss the emission reduction potential of enterprises or industries based on the forecasting results, while others explore the time of carbon peaking in some regions or industries to establish measures accordingly. The endogenous variables and exogenous parameters of the scenario setting also need to be studied.

Practical and Policy Implications

Based on the results of the analysis of carbon emission forecast research, we propose implications from two aspects: practical and policy.

Practical Implications

Extensive literature analysis shows that energy and industrial structure are important factors affecting carbon emissions, but only a very small number of studies have directly used measurement data on carbon emissions. Other studies make calculations through energy conversion coefficients or indirect ways. Effective methods to measure industrial carbon emissions can ensure the accuracy of subsequent carbon emission forecasting. The current mainstream methods are hybrid models, including time series, machine learning, or a combination of more methods. Based on the strengths of various methods, models are optimized to improve prediction accuracy, laying a foundation for the formulation of measures and policies. Joint multidisciplinary research could be conducted to gain a deeper understanding of the influencing factors, mechanisms of action, and evolutionary processes of carbon emissions. Based on the forecast results and scenario extrapolation, propose scientific and reasonable carbon emission reduction policies as well as

corresponding safeguard mechanisms and supervision mechanisms.

Policy Implications

Forecasting, controlling, and reducing carbon emissions involves complex systems engineering with multiple actors. Participants mainly include the central government, local governments, enterprises, scientific research institutions, and so on. These participants interlock with each other and have different degrees of effect.

Government sectors are not only the makers of emission reduction strategies, but also the planners and promoters of reduction. The government should improve administrative policies in the aspects of laws, standards, planning, and total control. Moreover, policies between central and local governments need to be coordinated, and all departments need to work together in order to effectively implement energy-saving and emission-reduction policies. Through adequate, effective, and flexible use of fiscal spending and tax policy changes to influence and regulate the optimal allocation of resources and establish a synergistic linkage mechanism of fiscal policy that combines positive guidance and negative constraints. Regulating the intensive and economical use of resources, forming a good situation where people and nature live in harmony. Promote the formation and sustainable development of a resource-intensive and environment-friendly society.

Scientific research institutes and industry associations can provide top-level designs for emission reduction and provide the basis for macroscopic decision-making for the government. It can also provide technical support, knowledge advice, and assessment of the effectiveness of emission reduction for enterprises.

As the main body of carbon emissions, enterprises should speed up to transformation and upgrade, and strengthen the supporting role of low-carbon technology. Carry out research on the optimization of energy system intensification, intelligence, and refinement of management technology. Establish a joint emission reduction collection of energy supply, raw material production, primary product processing, and downstream sectors to collaborate on energy laddering, material recycling, and production industrial improvement design to promote the green transformation of enterprises.

Conclusions

The bibliometric analysis of the existing literature on carbon emission forecast and the interpretation of many aspects of the literature provide some practical suggestions on carbon emission forecast for researchers in this field on carbon emission forecasting research.

From the perspective of forecasting methods: (1) The extensive literature analysis shows that energy and industrial structure are significant factors affecting carbon emissions. However, very few studies have directly used measurement data on carbon emissions, often relying instead on energy conversion coefficients or indirect methods. Recent research suggests that the use of direct measurement data can enhance the accuracy of carbon emission forecasts. (2) The prediction accuracy in carbon emission forecasting is closely related to the decomposition of influencing factors. The identification, screening, and weight assignment of these factors are crucial, and the latest studies emphasize the importance of scientific and reasonable selection of these factors for reliable predictions. (3) Current mainstream methods are hybrid models, including time series, machine learning, and combinations of various methods. Recent advancements have optimized these models, improving prediction accuracy. Furthermore, considering the economy, technology, and population, it is advisable to analyze the emission reduction potential and explore the timelines for carbon peaking and neutrality, thus laying the foundation for effective policy formulation.

From the perspective of research content and outcomes: (1) At the enterprise level, conducting carbon emission forecast reviews provides guidance for energy saving and emission reduction, enhancing environmental and social benefits. This ensures sustainable and environmentally friendly enterprise development. (2) From the government perspective, carbon emission forecasts help understand the current industrial situation, regulate key industries and regions, and control carbon emissions according to demand. Governments can optimize industrial structures and transform production and consumption patterns based on these forecasts. (3) At the national level, carbon emission forecasts aid in the development of relevant laws and regulations, clarifying carbon emission rights and responsibilities, and improving industry standards. They also strengthen international exchange and cooperation on environmental issues.

Reviewing and analyzing the existing research literature and discussing forecast methods highlights several key points for future carbon emission forecast research: (1) Relevant government departments should strengthen carbon emission statistics, standardize statistical methods, develop scientific definitions, address industry and regional overlaps, regularly release authoritative data, and establish comprehensive carbon emission monitoring systems to better serve socio-economic development. (2) There should be a focus on industry-specific carbon emission research, including sectors like construction, transportation, commerce, and personal consumption, in addition to industrial emissions. (3) Multidisciplinary research should be conducted to gain a deeper understanding of the influencing factors, mechanisms, and evolution processes of carbon emissions. Based on forecast results and scenario extrapolation, researchers should propose scientifically sound carbon emission reduction policies

and develop corresponding safeguard and supervision mechanisms.

In conclusion, the ongoing advancements in carbon emission forecasting methods and the increasing interdisciplinary collaboration highlight the importance of a comprehensive and inclusive approach. By integrating direct measurement data, refining influencing factors, and leveraging hybrid models, researchers and policymakers can develop more accurate and actionable forecasts. These efforts will ultimately contribute to more effective carbon emission reduction strategies, fostering sustainable development at enterprise, governmental, and national levels.

Limitations and Suggestions for Further Studies

This study has several limitations. We analyzed carbon emission forecast literature only from WoS, so results should be interpreted cautiously. Future research should include more sources like journals, books, and conference articles and incorporate non-English literature. Using multiple bibliometric tools could offer a more comprehensive analysis.

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Conflict of Interest

The authors declare no conflict of interest.

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