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Review

Bibliometric Analysis of Research Progress and Trends on Carbon Emission Responsibility Accounting

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Abstract: The severity of global climate change is a pressing issue, and carbon emission reduction requires collaboration between producers and consumers. Carbon emission responsibility accounting is critical for distributing the tasks associated with carbon reduction. To examine the current research status and future development trends of carbon emission responsibility accounting, we used the scientific quantitative knowledge graph method and CiteSpace software. We analyzed the data from 4089 studies retrieved from the Web of Science and China National Knowledge Infrastructure databases, focusing on various aspects such as the number of published papers, subjects, research focuses, research content, and future research directions. In 2022, the number of publications was 657. The largest number of published carbon emission responsibility accounting documents was published by scholars from China: there were 708 published articles, 35% of the 2002 articles published in the Web of Science. The reason may be that China, as a developing country, produces more carbon emissions. In order to actively shoulder international responsibilities and slow down global warming, China strengthened its research on carbon emission responsibility, the basic work on carbon emission reduction. This was followed by the United States and England. England showed high levels of research collaboration. "Environmental science" was one of the main subjects in the Web of Science database, representing 43.96% of total publications. Research focuses included input–output analyses and implied carbon export trade. This study summarizes the literature on carbon emission responsibility accounting in terms of research perspectives, accounting principles, and accounting methods. In the future, the accounting of carbon emission responsibility at the city level considering the carbon emission responsibility sharing method including three or more shared parties and accounting for the carbon emission responsibility between the upstream and downstream from the perspective of the industrial chain can be studied. The findings of this study provide guidance to researchers and policymakers for the progression and enhancement of carbon emission responsibility accounting.

Keywords: carbon emission responsibility accounting; literature metrology; research content analysis; CiteSpace; multi-region input–output method

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1. Introduction

Global climate challenges have garnered significant attention with global economic growth. Since 1992, numerous countries and regions worldwide have actively implemented measures to mitigate stress on the ecosystem caused by climate change, such as melting of glaciers and loss of biodiversity. In this context, the United Nations Framework Convention on Climate Change proposed the principle of "common but differentiated responsibilities" as a fundamental aspect of global climate governance in 1994. The escalation in global climate change can be attributed to the emission of greenhouse gases, particularly carbon dioxide [1]. The Paris Agreement, enacted in 2015, advocates for carbon neutrality and mandates member countries to take aggressive measures for decreasing emissions. The accord also aims to limit global warming to 1.5 °C and achieve the long-term objective of limiting global temperature increase to 2 °C. Moreover, it proposes that countries should be collectively held accountable for global carbon emissions [2,3].

The assessment report of the United Nations Intergovernmental Panel on Climate Change (IPCC) suggests that for achieving the long-term goal of limiting global average temperature increase to below 2 °C, carbon emissions should be reduced by 40–70% by 2050 compared to those in 2010, reaching almost zero emissions by 2100, which can mitigate the effects of global warming. Furthermore, to achieve this goal, carbon emissions should be precisely calculated and corresponding obligations should be allocated. However, economic globalization has led to a noticeable level of carbon emissions, accounting for division of labor in industries and resulting in considerable greenhouse gas emissions from economic trade between countries and local areas [4]. The transportation of products across regions also contributes to the emission of CO_2, which is generated throughout the process of manufacturing until the arrival of product at the consumer end, creating a complex carbon emission transfer [5]. This makes it challenging to precisely assign responsibilities for carbon emissions, which in turn complicates the concept of "common but differentiated responsibilities" [6,7]. Nevertheless, commerce and trade between regions are inevitable. Hence, a reliable carbon emission accounting scheme should be established, requiring immediate attention to achieve "common but differentiated responsibilities".

The concept of carbon emission responsibility accounting has gained massive global attention. The primary economic activity in Denmark is import/export trade, attributable to its open economy. This results in considerable variances in carbon emission responsibility accounting [4]. To resolve discrepancies between consumer and producer accounting methods, some Italian researchers have proposed a technique for evaluating carbon emissions utilizing implicit energy analysis [8]. From 1996 to 2006, in the United Kingdom, imports increased significantly by 128%, whereas exports exhibited only a moderate increase of 65%, highlighting the status of the United Kingdom as a leading consumer nation [9]. Developing countries have opposed the proposal of the European Union (EU) to include global aviation emissions in its carbon market scheme, stating that it contravenes the principle of "common but differentiated responsibility". To address this issue, consumer nations could assume liability for emissions resulting from worldwide cargo transportation [10,11]. In Norway, CO_2 emissions stem mainly from its exports of harmful substances (accounting for 69% of the nation's total emissions) [12]. Thus, accounting for carbon emission responsibility based on consumers' principles can reduce implicit carbon emission responsibility in Norway's export process and aid in establishing a fair distribution of producer and consumer responsibilities [13]. Globally, China is the largest contributor to atmospheric CO_2 emissions [14]. In 2022, the State Council of the People's Republic of China released the "Action Plan for Carbon Peak before 2030", aiming to improve the capacity for the statistical accounting of carbon emissions, upgrade the accounting methods, and establish a fairer and more reasonable carbon emissions accounting system. The scientific and practical calculations of inter-provincial carbon emission obligations have become crucial for advancing the system [15,16].

Few studies have employed bibliometric analyses to review the literature on carbon emission accounting. Based on a review of articles from the Web of Science Core Collection, Li et al. examined the current state of development, distribution of research strengths, and focuses of research on carbon emission responsibility allocation [17]. Similarly, Zheng et al. investigated the trends and characteristics of carbon accounting in the realm of social sciences using the Web of Science database [18]. These two studies offer valuable recommendations for more comprehensive research on carbon emission responsibility accounting. However, these studies have certain limitations, as they have solely analyzed overseas research, disregarding local and comparative research at both China and international levels. Furthermore, Zheng et al.'s study did not focus on carbon emissions responsibility accounting. Li et al.'s study focused on the allocation of responsibility for carbon emissions.

Generally, carbon emission responsibility accounting is crucial for clarifying the responsibilities of all parties and realizing "common but differentiated responsibilities".

However, contemporary research in this field has some deficiencies. To overcome them, this study utilizes bibliometrics and CiteSpace software to analyze the status of the existing research and provide research directions for future developments in carbon emission responsibility accounting. The dataset in this study comprises 2002 English-language publications from the Web of Science database and 2087 Chinese-language publications from the China National Knowledge Infrastructure database (Figure 1). This study addresses the following questions in the field of carbon emission liability accounting:

(1) How many articles have been published?
(2) Which topics have been covered?
(3) What are the specific research contents of existing literature?
(4) What are the future research directions in this field?

The novelty of this study lies in the following aspects: first, to acquire more thorough results, this study supplements the current English-language literature with Chinese-language literature. A thorough search on the Web of Science and China National Knowledge Infrastructure databases was performed to investigate research trends in the carbon emission responsibility accounting field. Second, this study focuses on carbon emission responsibility accounting and selects most relevant Chinese and international literature using several search strategies, making the literature data more comprehensive and accurate. Finally, it combines quantitative and qualitative analyses to compensate for the lack of subjectivity of qualitative analyses. Overall, this study offers an in-depth understanding of the theoretical basis, methodology, and practical applications of carbon emission liability accounting, providing strong support for further research. This study discusses the specific content of future research, providing significant guidance for improving the carbon emission trading market and formulating policies related to carbon emission reduction.

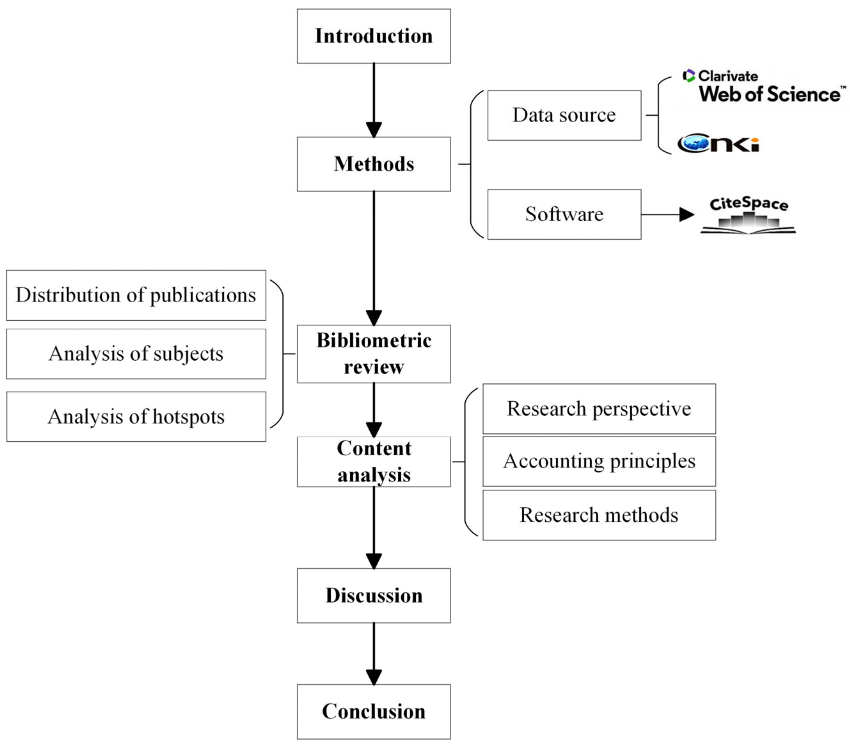

Figure 1. Structure sequence of the study.

This article is structured as follows: Section 2 presents the materials and methods; Section 3 presents the bibliometric review of studies on carbon emission responsibility accounting; Section 4 presents the content analysis of studies on carbon emission responsibility accounting; Section 5 discusses the future new research directions; finally, Section 6 summarizes the research conclusions.

2. Materials and Methods

2.1. Research Method

This study employs CiteSpace (6.1.R6), a visualization analysis software, to evaluate the present state, institutional allocation, key areas, and trends in policy investigation in China. CiteSpace was developed within the context of scientific metrology and data visualization, with an extensive theoretical grounding [19]. Furthermore, a co-occurrence analysis and literature review were conducted to collect information of the publishing institutions, authors, and keyword nodes in the field of carbon emissions responsibility accounting. To analyze the emerging trends and prevalent issues in the research on carbon emission responsibility accounting, a table was generated using the keyword emergence graph.

2.2. Research Data

2.2.1. English Literature Data

This study selected the “Web of Science Core Collection” as the search database, limiting the “Citation Index” to the Social Sciences Citation Index and the Science Citation Index Expanded. To ensure the precision of the results, advanced search options were utilized, which offered additional criteria. Following several tests and professional advice, this study used the following keywords for search: “((TS = (greenhouse gas OR carbon OR CO_2 OR carbon dioxide OR greenhouse gas emissions *)) AND TS = (responsible *)) AND TS = (account * OR calculation * OR measurement OR allocation * OR distribution * OR pattern OR principal OR sum * base * OR product * base * OR income base * OR sum * OR income OR share * OR common)” in the “Retrieval Preview” box of the “Advanced Search” page. The publication date was customized to be in the range from 1 January 2000 to 31 February 2022; the type of document was limited to “dissertation” and “review paper”; and the language was set to “English”. Items from 2002 were obtained following a rigorous screening process conducted by independent second parties, followed by verification by a third party. No limitations were placed on the publisher or research focus. All data were exported in the plain-text file format.

2.2.2. Chinese Literature Data

The “Advanced Search” function was used for topic search to ensure that the data were comprehensive and accurate. The “Academic Journals” database was selected for search. After careful consideration of advice from professionals and several trials, we limited our search to specific topics, namely “(carbon emissions + carbon emission reduction + CO_2 + carbon footprint + carbon dioxide) * (responsibility + production responsibility + revenue responsibility + income responsibility + consumption responsibility + shared responsibility)” OR “topics” to “implicit carbon emissions + carbon emission reduction responsibility + carbon transfer + shared responsibility” literature. The study utilized 2306 pieces of data collected through the “All” source category and selected synonym extension up until 2022. Literature data that lacked authorship and pertained to law, materials, accounting, medical, and news distribution were excluded, resulting in a final validated dataset of 2087 articles. This dataset was verified by a neutral third party. The files were subsequently exported in RefWorks format. On 19 July 2023, all searches pertaining to the study were completed.

To process the exported data from the China National Knowledge Infrastructure database for analysis, this study utilized the data converter built into CiteSpace. The converted data were then screened to ensure accuracy. Duplicate data from the Web of Science were excluded based on the “All” de-duplication standard, and data from the China National Knowledge Infrastructure database were filtered.

The detailed research process is illustrated in Figure 2.

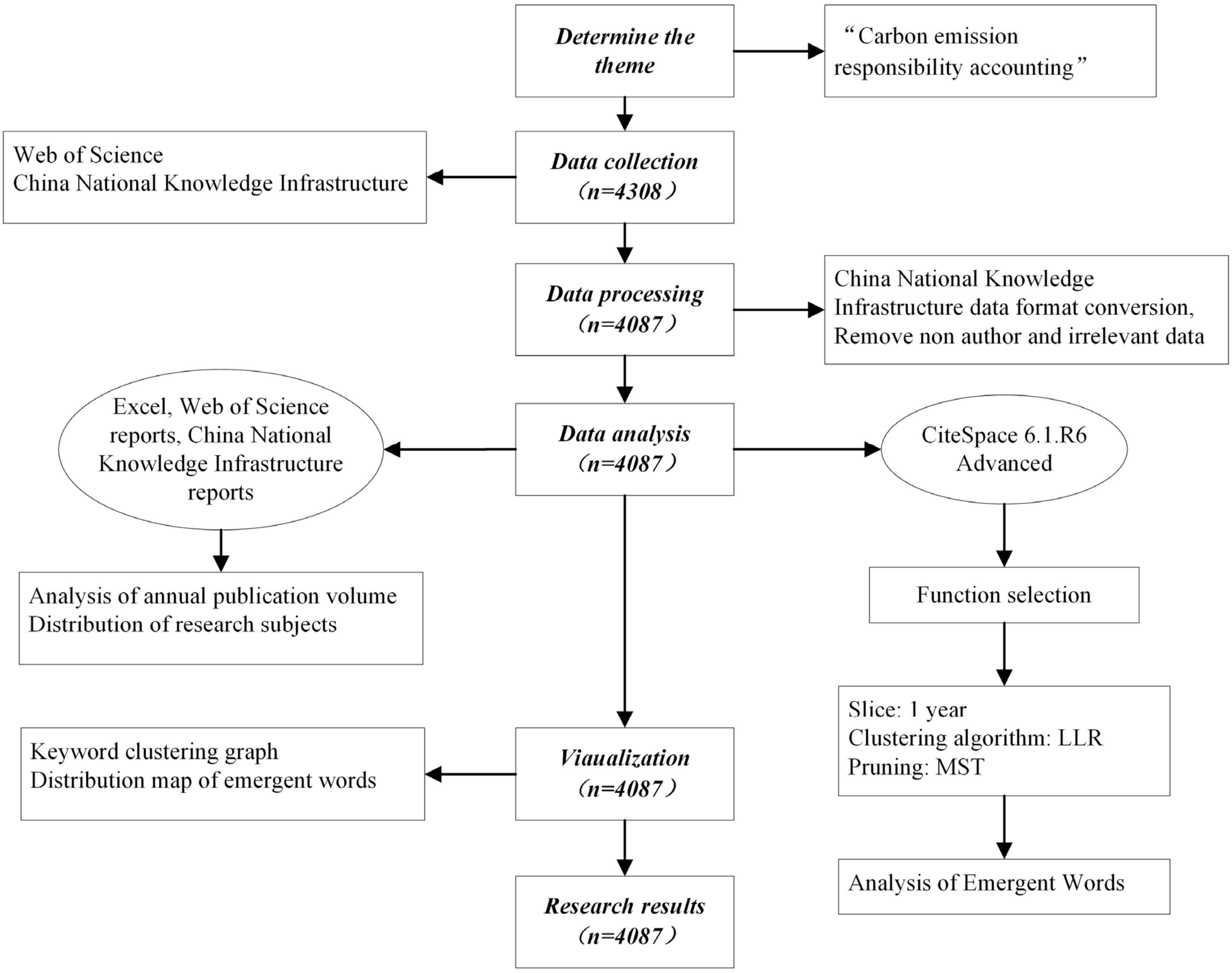

Figure 2. Bibliometric analysis flow diagram.

3. Bibliometric Review of Carbon Emission Responsibility Accounting Study

3.1. Analysis of Publications

3.1.1. Number of International Publications

Figure 3 displays the publications on carbon emission responsibility accounting. Between 2000 and 2022, the number of publications in this field exhibited an increasing trend, implying a rising worldwide concern. To facilitate understanding, the annual output was divided into the following four stages: the exploration stage (prior to 2004), the starting stage (2005–2009), the preliminary development stage (2010–2017), and the rapid development stage (2018–2022), as depicted in Figure 3a. From 2000 to 2004, this topic garnered limited interest from non-China researchers, as evident from the number of annual publications during the period, which was only 10. However, since then, the trend has changed. The number of publications in 2005 was 10.33 times higher than that in 2004, and the number increased consistently from 2008 to 2009. Most of the studies focused on initial evaluation. Between 2010 and 2017, there was a restriction in research, yet researchers continued to investigate and make progress, leading to an unstable condition of fluctuating publication output. Nevertheless, the impact of this restriction on the overall upward trend was minimal. In 2010, the number of publications increased by 83% compared to 2009, marking the year with the highest growth rate. Since 2018, there has been a consistent increase in the number of publications annually, resulting in an immense increase in the total number of publications. The year 2022 recorded 359 publications, the highest number to date, indicating the growing trend of research on carbon emission responsibility accounting. The number of publications is expected to continue increasing in the future.

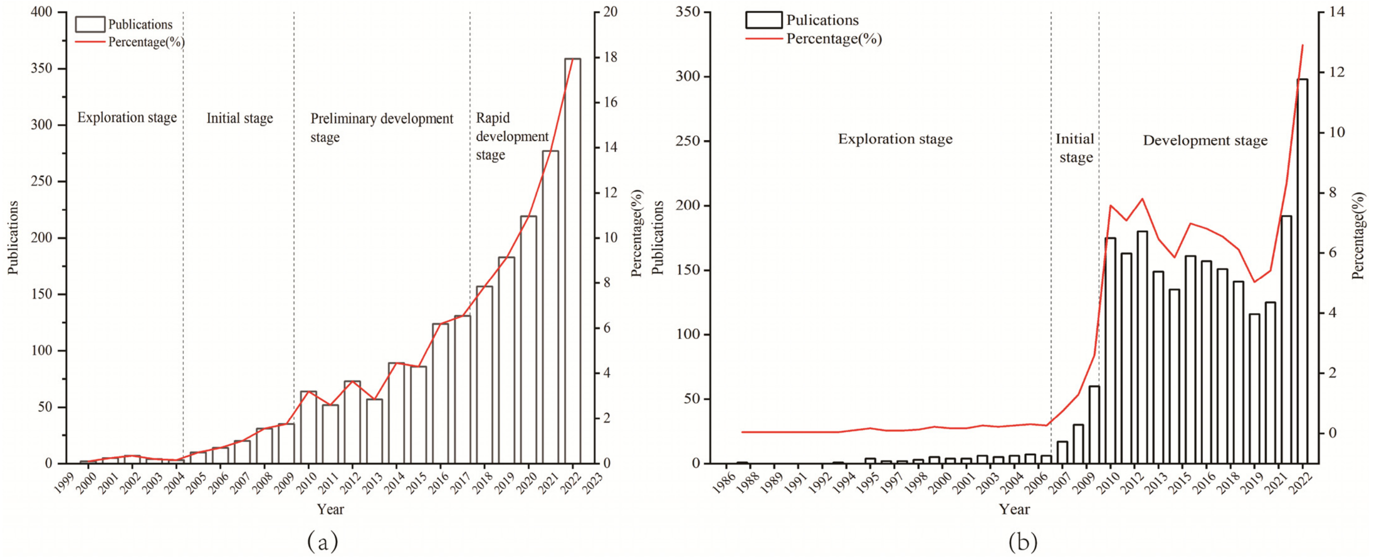

Figure 3. Number of annual publications on carbon emission responsibility accounting. (**a**) is the number of international publications, and (**b**) is the number of Chinese publications.

3.1.2. Number of China publications

Figure 3b illustrates the annual publication volume in China. Based on the yearly output, the study period was divided into three stages: the discovery stage (prior to 2006), the starting stage (between 2007 and 2009), and the development stage (between 2010 and 2022). Between 1985 and 2006, the topic received limited attention in China, as the annual publishing volume was negligible in the 1990s, with only one publication in 1987 and one in 1993. The yearly publication rate was modest, with an average of <10 papers between 1995 and 2006. However, this trend changed during the preliminary stages of the investigation, as evidenced by 17 publications in 2007—a staggering 183.33% increase. This phase displays a growing trend consistent with the continuous increase in the number of publications on the Web of Science database. A plethora of articles were published between 2010 and 2022, constituting 92.92% of the total during the entire research period. Since 2010, significant research has been conducted by China scholars. The pioneering study was conducted in China [20]. The number increased significantly in 2021, denoting an 8.33% increase from the previous year, followed by a subsequent surge in publication volume. In 2022, 298 articles were published, marking the largest volume of publications in history, with a 12.92% increase compared to the previous year. This notable growth rate is anticipated to continue, in alignment with China's dual-carbon goals.

3.2. Analysis of Subjects

The field of carbon emission responsibility accounting encompasses various aspects. Figure 4 displays the top 10 areas of research focus at the international level. Of the total articles published in 2002, 880 were in the field of environmental science, 548 in ecological research, and 434 in green sustainable technology, representing 43.96%, 27.37%, and 21.68% respectively, of the total number of publications. Other crucial disciplines in this research field included engineering environment, economics, and energy fuels.

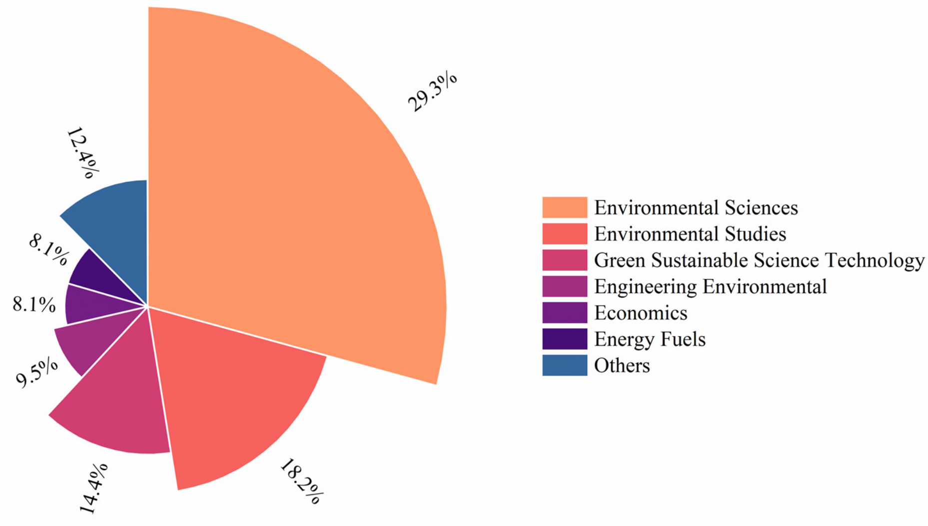

Figure 4. Distribution of research topics.

3.3. Analysis of Research Focuses

3.3.1. International Research Focuses

The modularity value (Q) of the clustering module > 0.3 indicated a clustered structure, and the Silhouette value (S) was used as a measure of the reliability of the clustering [21]. Q > 0.5 indicated that the module could be trusted; S > 0.7 suggested strong clustering [19]. When Q and S values were 0.5217 and 0.8061, respectively, it was inferred that the members within each cluster were sufficiently consistent in the Web of Science. The reliability of the keyword clustering graph was high, and the classes were strongly interconnected. The lower the cluster number, the higher the availability of the academic literature on the subject. The top 10 areas of research interest based on publications in the Web of Science databases are presented in Table 1.

Table 1. Keyword clustering of research on carbon emission responsibility accounting in the Web of Science.

Cluster-ID	Size	Silhouette	Mean (Year)	Cluster Header	Main Cluster	Representative Literature
#0	101	0.81	2011	Input–output analysis	International Trade; Structural decomposition analysis; China; Structural path analysis	[22–26]
#1	86	0.787	2016	Corporate social responsibility	Environmental performance; Corporate governance; Carbon disclosure; Financial performance	[27,28]
#2	70	0.804	2009	Climate change	Climate policy; Burden sharing; Policy; Carbon accounting	[29–31]
#3	64	0.725	2016	Circular economy	Life-cycle assessment; Waste management; Recycling; Supply chain management	[28,32]
#4	49	0.769	2014	Industrial sectors	Target; Model; Marginal abatement cost; International trade	[33,34]
#5	48	0.788	2013	Air pollution	Ecosystem services; Livelihoods; Inequity; Multinational enterprises	[35–38]
#6	43	0.831	2014	Willingness to pay	Renewable energy; Energy transition; Electric vehicles; Governmentality	[39,40]
#7	41	0.729	2013	Climate justice	Migration; Climate finance; Bottom-up approach; Household	[41]

Table 1. *Cont.*

Cluster-ID	Size	Silhouette	Mean (Year)	Cluster Header	Main Cluster	Representative Literature
#8	27	0.879	2016	Carbon leakage	Border carbon adjustment; Emission accounting; China carbon adjustment; Border carbon adjustment	[13,42–44]
#9	18	0.944	2011	Net global carbon flows	Environmental Kuznets curve; Trade and environment; Fertilization; Peak coal consumption	[45]

This study examined the trend in two research focuses. Cluster #0 was titled "Input–Output Analysis"; it utilized the standard technique for estimating carbon emissions resulting from trade. Input–output data were used to represent economic linkages within and between various departments or countries. Research on carbon emission accounting based on consumer principles gained momentum due to potential issues with carbon leakage based on producers' principles. Cluster #1 was titled "Corporate Social Responsibility", wherein environmental performance analysis was used to evaluate the overall interaction between the economy and the environment. Scholars have placed significant emphasis on the implicit carbon emissions arising from economic growth and energy usage. The implicit carbon emissions were calculated using the input–output analysis, directional distance function, data envelopment analysis, and other methodologies. Among these, the input–output analysis can be used to accurately define the responsibility for carbon emissions at the industrial level.

3.3.2. Focuses of China Research

When the mean Q and S values were 0.6063 and 0.8731, respectively, the components of each cluster were deemed to be adequately consistent. The keyword cluster graph was reliable, and Table 2 presents the clustering outcomes. By examining and summarizing keywords from each cluster, this study categorized 28 main topics. Table 2 presents the top 5 research focuses in the China National Knowledge Infrastructure database. "Implied carbon export trade" is the theme word for Cluster #0. The direct computation of carbon emissions leads to an overestimation of actual carbon emissions while overlooking implicit carbon emissions. The primary culprits of carbon emissions in China are the manufacturing and building sectors, and scholars are concentrating on carbon emission responsibility accounting in the construction industry.

Table 2. Keyword clustering of research on carbon emission responsibility accounting in the China National Knowledge Infrastructure.

Cluster-ID	Size	Silhouette	Mean (Year)	Cluster Header	Main Cluster	Representative Literature
#0	61	0.863	2013	Implied carbon export trade	Export trade; Input–output; Foreign trade; Input–output method	[46,47]
#1	56	0.908	2012	Low-carbon economy	Social responsibility; Information disclosure; Carbon accounting; Low carbon	[48]
#2	47	0.787	2013	Carbon reduction	Carbon trading; Global warming; Low carbonization; Game Theory	[49,50]
#3	46	0.88	2012	Climate change	Carbon emission rights; Greenhouse gases; The principle of fairness; Climate justice	[1,20,51]
#4	43	0.803	2010	Responsibility for emission reduction	Low-carbon development; Carbon emissions; Cost of emission reduction; Implied carbon	[52,53]

Table 2. *Cont.*

Cluster-ID	Size	Silhouette	Mean (Year)	Cluster Header	Main Cluster	Representative Literature
#5	38	0.834	2014	Carbon emissions	Carbon footprint; Carbon tax; Energy conservation and emission reduction; Environmental effect	[54]
#6	33	0.904	2012	International trade in the industrial chain	International trade; Low-carbon emission reduction; Value chain; Industrial upgrading	[55]
#7	20	0.961	2018	Carbon neutrality	Carbon peaking; Climate governance; The Belt and Road Initiative China's response	[56]
#8	19	0.901	2011	Carbon transfer	Carbon peaking; Climate governance; The Belt and Road Initiative China's response	[57,58]
#9	18	0.942	2015	Shared responsibility	Dual carbon targets; Developed countries; Training mode; Public responsibility	[59]
#10	18	0.914	2011	Carbon tariffs	Low-carbon products; Empirical analysis; WTO; Legitimacy	[60]
#11	16	0.928	2017	Low-carbon transformation	Green finance; Emission reduction path; Principal responsibility; Business strategy	[61]

4. Content Analysis of Studies on Carbon Emission Responsibility Accounting

4.1. Research Perspectives

After a thorough examination of the literature, this article provides an analysis of three key elements: research perspective, accounting principles, and research methods, as illustrated in Figure 5.

4.1.1. International Perspective

Research on carbon emission responsibility accounting has been conducted primarily from two perspectives—global and China. Scholars have analyzed indirect carbon emissions resulting from international commerce through a global lens [62–66]. Callahan et al. argued that countries with high income and high emissions benefit at the expense of low-income and low-emission countries that experience the inherent injustice in the causes and effects of historical warming [67]. Both developed and developing countries must share the responsibility of reducing carbon emissions [68,69]. Developing countries can achieve more effective carbon reduction measures by implementing stronger Chinese modifications rather than international ones [70].

Economic trade between countries is the main source of implied carbon emissions, and carbon emission responsibility accounting of special countries, such as importing and exporting countries, has received extensive attention from scholars [71,72]. For exports, greater congruity between international and Chinese carbon adjustments implies a greater likelihood of reducing carbon emissions' energy usage intensity. For China's exports, the implied carbon from net exports is as high as 298 million tons [1], and the patterns of import and export trade and the structure of export trade [65] are the key factors affecting implied carbon emissions. For China's imports, scholars believe that the scope of reducing carbon emissions from imports is high, which means that c carbon emissions from exports can also be reduced [72].

As global agents, multinational corporations play a pivotal role in the environmental impacts of waste through their corporate governance structure [73], foreign investment [74], and so on. Accurate accounting of multinational corporations' carbon liability can enable a precise estimation of carbon footprints of each country (the controlling country of multinational corporations), which holds great significance for accounting of national carbon liabilities, their allocation, and differentiated foreign investment strategies [75,76]. An influencing factor for the implicit carbon emissions of international trade is the tariffs that lead to an increase in CO_2 emissions from worldwide fuel burning, especially in some developing countries [77].

Extensive research has been conducted on carbon emission responsibilities at both macro and micro levels, covering different countries and multinational corporations, respectively, laying a foundation for further research from an international perspective.

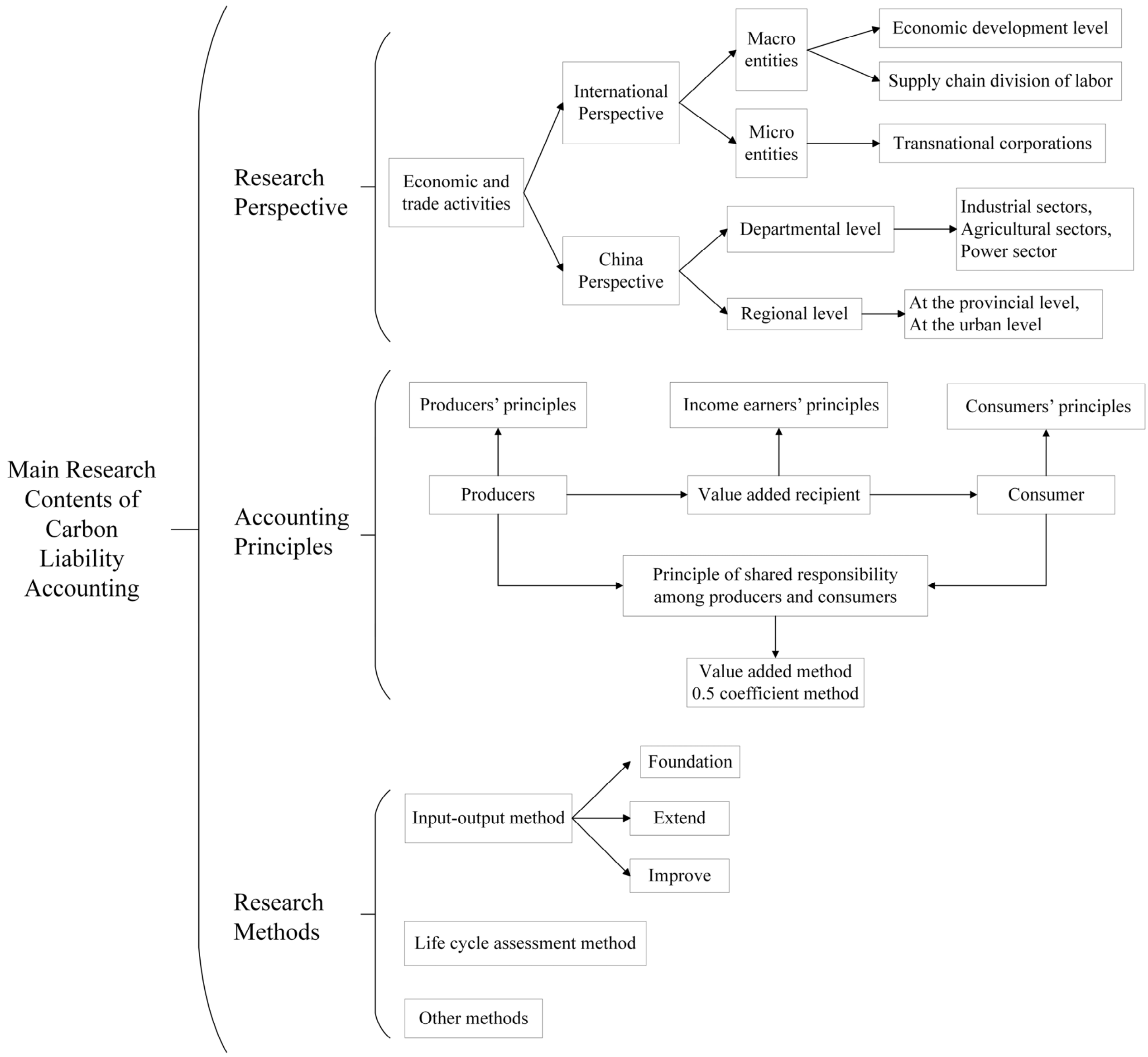

Figure 5. Schematic of the analysis of relevant literature.

4.1.2. China Perspective

The production activities of commodities contribute primarily to carbon emissions. Consequently, scholars have focused on carbon emission responsibilities of agriculture and electrical industries, and further research in this domain for different industry sectors and departments is ongoing [78,79]. In the industrial sector, He et al. conducted a theoretical investigation into the willingness of Chinese electric vehicle battery suppliers and manufacturers to engage in green cooperation, which offers insights for the low-carbon and green development of the battery industry chain [80]. Specifically, Li et al. investigated greenhouse gas emissions from the distribution networks of iron-containing commodities [78], as well as the from nickel [79], cobalt [81], retail [82], iron and steel [83], and waste product recycling industries [84]. Presumably, oil, coking, gas, and precision product processing industries jointly contribute to 25.89% of construction emissions [85]. Researchers in the agriculture field have evaluated carbon emissions and associated reduction costs pertaining to the planting industry. They proposed a mechanism for distributing responsibility to reduce carbon emissions [86]. Wood, a crucial component in the process of carbon reduction, has a large consumer base in industrialized nations which have a high demand for carbon stocks in this material, whereas developing nations serve as the primary producers of wood [65]. The estimation method of implied carbon emissions in the power sector primarily relies on the computation of IPCC coefficients [87–89]. Energy consumption is the main source of carbon emissions, and improving energy use intensity is an effective means to reduce carbon emissions [90].

Research at the industrial level is insufficient to meet the needs of further development of carbon emission responsibility accounting. To obtain more comprehensive insights, scholars have conducted research at the regional level [57,91–94] as well as at the provincial level [86,95–98]. Qian et al. indicated that carbon emissions will increasingly be the responsibility of developed provinces in northern China [99]. The findings of these studies vary significantly because of the chosen criteria, with the "consumer responsibility for incentive compensation" criteria being scientifically valid [97]. Recent research has focused on the urban sphere [100,101].

China research in this field has shifted its focus from the industry level to the provincial level, deepening further to the city level, thereby forming a relatively perfect research system which helps comprehensively understand carbon emission responsibility accounting at the China level; however, some gaps still remain to be addressed.

4.2. Accounting Principles

The concept of carbon emission responsibility accounting is based on various principles including those based on objective accounting, producers, consumers, income earners, and shared responsibility among producers and consumers. However, regardless of the accounting approaches, sectoral aggregation schemes significantly impact the accuracy of carbon emission responsibility accounting. Sectors aggregated on the basis of energy, emissions, and trade intensity can substantially reduce errors [102].

4.2.1. Producers' Principles

Production activities involving the use of high-carbon emission materials or energy serve as the primary source of carbon emissions [103]. Scholars have mainly used the IPCC method to achieve carbon emission responsibility accounting based on producers' principles; this method considers the product of energy or material usage and its carbon emission coefficient. The accounting method is simple and practical and has been widely used in academia and practice. By acknowledging the role of producers in contributing to carbon emissions, it serves as an initial approach to attributing responsibility for carbon emissions and thus is a crucial starting point for carbon emission accountability. This method only considers the carbon emissions generated during production activities while ignoring the final destination of the produced goods. It assigns all carbon emission responsibilities to producers and does not consider the responsibilities of other "contributors" such as consumers, inadvertently placing undue carbon emission responsibilities on producers and leading to inaccurate allocation of carbon emission accounting. Therefore, the current method of allocating carbon emission responsibilities is not fair and requires modifications.

4.2.2. Consumers' Principles

The consumers' principle has been widely adopted by scholars. According to economic theory, demand drives supply, and vice versa, highlighting the significance of consumer demand in trade. The principle of "who consumes, who bears" underlies the accounting of carbon emission responsibility, rendering it a frequently employed approach [63,70,104–110]. Japan as a consumer and China as a producer should undertake carbon reduction obligations through measures such as technical support [111]. Implementing consumers' principle in accounting for carbon emissions can lead to better efficiency and is more justifiable [112].

Consumer demand, being the primary driver of the production of goods and carbon emissions, is not the sole factor, and considering only the consumers to be accountable for carbon emissions is unjustifiable. The consumers' principle assigns the entire responsibility for carbon emissions to the consumer while overlooking producers' responsibility [113]. Zhang et al. and Pan et al. compared and evaluated the principles based on producers' and consumers' end [114,115]. Given that this principle poses challenges for producers, the producers' principle seems more pragmatic and straightforward.

4.2.3. Income Earners' Principles

The income earners' principle constitutes another pivotal principle of allocating responsibility of carbon emissions, and it was introduced after the principles based on producers and consumers. In the trade of merchandise, production factors such as capital, plant, labor, and land must share the responsibility for carbon emissions. This is plausible because the different factors of production, provided by suppliers, facilitate the production of goods. Research based on the income earners' principle is limited [43,116,117] and has received insufficient attention from scholars. An accounting model based on the consumers' principle is the Leontief matrix, whereas that based on income earners' principles is the Ghosh model [44]. Consumers' and income earners' principles have higher data requirements than the producers' principle, requiring more complex calculation processes and their results being accompanied by more uncertainties.

4.2.4. Principle of Shared Responsibility among Producers and Consumers

The responsibility for carbon emissions should not be apportioned exclusively to producers, consumers, or income earners, but it should be shared between producers and consumers. Currently, there is a consensus on the shared responsibility concept between producers and consumers among scholars [54,68,118–120]. Further, Zhang et al. asserted that exports account for a large proportion of implied carbon, and the means of foreign trade development should be transformed to a green trade system [52]. Zhang et al. proposed a benchmark technique for community-based carbon emission reduction that promotes multi-party engagement, thus providing a fresh perspective on carbon emission responsibility accounting [119].

Scholars have analyzed various sharing approaches. In academic discourse, two main methods exist, namely the value-added approach and the 0.5 coefficient method (Table 3). Initially, the 0.5 coefficient method was the most widely used approach in research on shared responsibility. Several scholars contend that responsibility should be equally shared between producers and consumers [51,58,89,121]. Later, with the gradual deepening of their understanding of shared responsibility among producers and consumers, scholars considered it more reasonable to determine the sharing coefficient based on the proportion of added value in trade between both parties; however, they used different methods for determining the ratio [53,55,71,122–124]. Peters believed that the sharing coefficient should be determined based on the ratio of the value added to the net output [13]. Recently, Wang proposed that the sharing coefficient can be determined by the ratio of the total amount of added-value outflow to the bilateral added-value outflow [125]. Overall, the number of methods for determining the sharing coefficient is constantly increasing, and the methods are being refined to be more scientific and practical, laying a solid foundation for accurate carbon emission responsibility accounting; however, there remains room for further development.

For evaluating the available methods, scholars have compared the techniques based on producers' principles, consumers' principles, and the principle of shared responsibility between producers and consumers [65,78,89,126]. She et al. contended that the implicit carbon emissions calculated based on the principle of shared responsibility between producers and consumers fall between those calculated using the two other methods [47], providing a more equitable accounting standard. Moreover, they pointed out significant variations in the carbon emission patterns across industries, attributable to the differences in the principles employed. The evaluation of environmental impacts should encompass three key parameters: productivity, land utilization, and energy consumption [11]. Consumers' principles, income earners' principles, and the principle based on shared responsibility between producers and consumers, especially those based on consumers and income earners, can all be accounted for using the input–output method. Overall, the consumers' principle is more practical and developed than the principle based on shared responsibility between producers and consumers, which is still in the nascent stages and has triggered debates on sharing methodologies.

4.3. Accounting Methods

4.3.1. Input–Output Method

Energy consumption, input–output, and trade data have been used by researchers to examine a country's import trade-related carbon, export trade-related carbon, and carbon balance [11,23,38,90,102]. In the late 1970s, Leontief integrated environmental considerations into the input–output model to evaluate the ecological impacts of economic activities [127]. Subsequently, the input–output model has advanced considerably. The model's assumptions have been relaxed, relevant data have been gathered, and it has progressed from a single-region to a multi-region phase. Consequently, the accuracy of the measurement results has improved.

Early scholars used a single-region input–output model to examine the implicit carbon liability, which assumed an equivalent consumption coefficient both in China and overseas and made no distinction between Chinese and imported products. With the expansion of global trade, China's position as the world's leading industrial center is becoming increasingly prominent. Imports also account for a greater proportion of the overall production of China goods. Therefore, it is essential to develop a new model that distinguishes between imported and exported goods and recalculates carbon emission accountability. The multi-region input–output model accounts for the differences in carbon emission responsibility for import and export product trades for each trading entity, resulting in more precise accounting compared with that computed using the single-region input–output model.

Multi-region input–output methods and models have been frequently employed in the studies on carbon emission responsibility accounting [69,72,128]. Scholars have also integrated the input–output approach with other methods, including the zero-sum gains—the data envelopment analysis [129], and the input–output theory—the row arrange series method [85]. The input–output method has also undergone various modifications [59,130,131]. Numerous academics have also employed Peters et al.'s approach [132], utilizing the input–output analysis to determine carbon emission responsibility and conducting decomposition analyses using the structural decomposition analysis tool [90,110].

After more than 50 years of development, the input–output method has evolved from being limited to a single region to being a multi-region method, and a combination of multi-region, input–output model and other models has been developed. With further development and refinement of the method, the accuracy of the accounting results of carbon emission responsibility has improved [125,131].

4.3.2. Other Methods

To assess the environmental effects of a complete process, the life-cycle assessment methodology is commonly employed in academia, which comprises the following four stages: defining objectives and scope, analyzing the inventory of the life cycle, interpreting the impacts of the life cycle, and reporting, which precisely reflects the environmental impact value of every stage, energy source or substance. Scholars have highlighted the importance of using the life-cycle assessment technique for a comprehensive renewable energy analysis [79,81,130,133]. Meftah et al. provided technological support to accurately account for carbon emission responsibilities [134]. Murthy et al. improved the distribution of tasks involved in handling non-hazardous electronic waste [135]. Baker et al. and Zhang et al. studied the spatial transport of carbon emissions. Scholars have also focused on the emission of other greenhouse gases [136,137], such as SO_2 [107,137]. Wood et al. calculated greenhouse gas emissions based on the producers' principle [107], focusing on accountability and on gases other than carbon dioxide. They underscored the relevance of their findings for reducing overall emissions.

Table 3. Summary of shared principles and methods.

Sharing Method	Literature	Specific Sharing Methods	Research Perspective
Value-added method	[13]	Value Added/Net Output	International
	[48]	Added Value Of This Department/(Total Investment; Self-Sufficient Investment)	China
	[71]	The Proportion Of Non-Factor Intermediate Investment From Other Industries To External Investment In a Certain Industry	International
	[122]	Value Added/(Gross Output Intra Industry Transactions)	China
	[55]	Value Added/(Total Output Intradepartmental Transactions)	Provincial level
	[123]	Value-Added exports/(Value-Added exports + Value-Added Imports)	International
	[124]	Provincial Value Added/Total Product Outflow	Provincial level
	[53]	Total Value-Added Outflow/Bilateral Value-Added Outflow at Provincial Level	Provincial level
	[125]	Value Added In Commodity Outflows/Total Value Added In Bilateral Commodity Outflows	Provincial level
0.5	[58]	0.5	Provincial level
	[89]	0.5	Provincial level
	[51]	0.5	Provincial level
	[121]	0.5	International
Others	[111]	Consumers In The Importing Nation Are Responsible For The Import Of Finished Goods, Whereas Importers' Producers Value Intermediate Inputs	International
	[16]	Consumer Surplus Ratio	Provincial level
	[138]	Provincial Gross China Product	Provincial level
	[117]	Technical Difference Allocation Method	International
	[139]	Carbon Tariff Rate	China
	[8]	Carbon Emission Increase/Total Carbon Emissions	International
	[140]	60%	China
The field of electricity	[87]	1-(Equivalent Value Of Electricity/Equal Value Of Electricity)	Provincial level
	[47]	Value Added Of Various Industries/(Total Output–Intra-Industry Transaction Volume)	International
	[88]	1-Electricity Equivalent Value/Electricity Equivalent Value	China

Emissions embodied in the bilateral trade approach, as outlined in [132], is an effective method for computing carbon emission accountability. This approach explicitly assigns carbon emissions from the transit processing re-export component to the re-exporting countries. In contrast, the multi-region, input–output method allocates such emissions to the end-consumer countries, thereby providing more precise calculations.

Overall, the multi-region input–output method is the predominant approach for computing carbon liability accounting. Integrating the input–output theory with other theories, such as game theory, can improve the accuracy of carbon liability accounting outcomes.

5. Discussion

By extracting emerging terms, we determined the current and future research trends. We sorted all burst keywords by the beginning year of burst [141]. As shown in Figure 6, the academic community's interest in "environmental disclosure", "quality", and "gender differences" has increased dramatically in recent years, highlighting that these aspects may be the focus of future research. With increased public awareness about environmental protection, environmental information disclosure has become a social obligation of businesses, similar to the monitoring of carbon emission reductions. As shown in Figure 7, future studies should focus on the carbon market, green financing, and carbon trading. In contrast to the focus of international research, Chinese research has examined both carbon emissions rights and green financing in light of circumstances in real time, in addition to accounting for the implicit carbon emission responsibility among traders. The allocation of carbon emission obligations is based on the distribution of carbon emission rights. China uses both the market and the government to regulate carbon emissions. Since 2020, green finance has gained prominence, offering financial support for reducing carbon emissions, and it remains a significant domain in Chinese research.

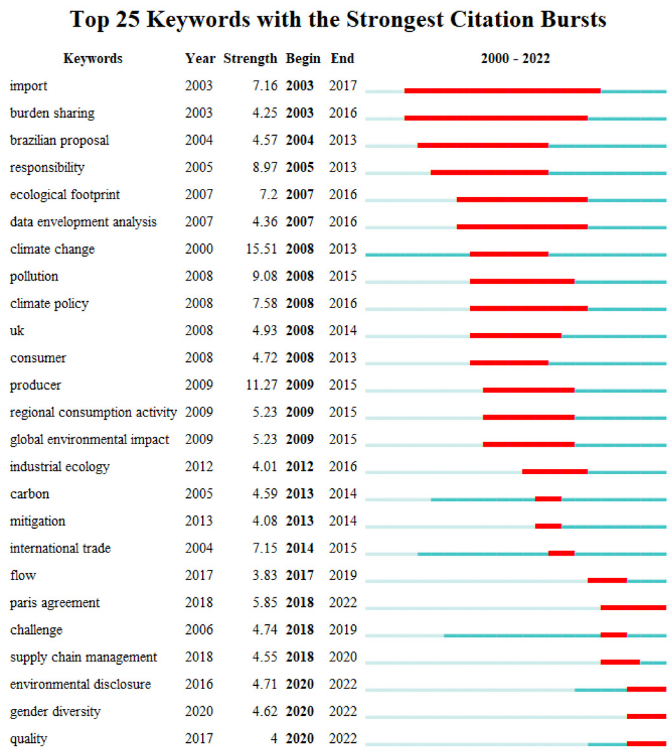

Figure 6. Top 25 keywords with the strongest citation bursts in the Web of Science.

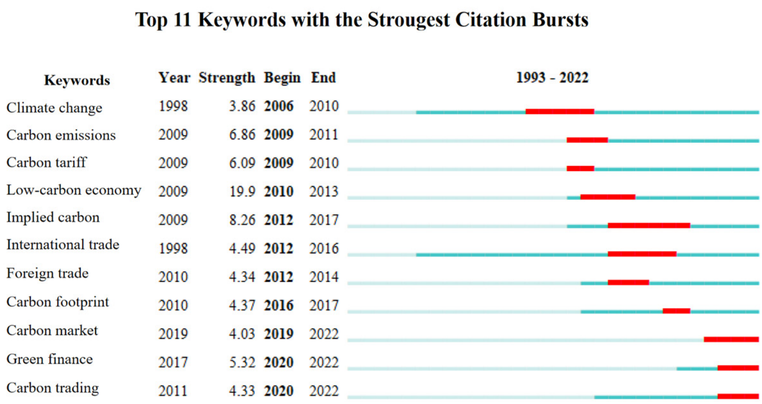

Figure 7. Top 11 keywords with the strongest citation bursts in the China National Knowledge Infrastructure.

Based on the previous literature quantity analysis, subject distribution analysis, specific research content analysis, and new research direction analysis of the literature data in the field of carbon emission liability accounting, we discussed in detail the possible future research content.

From the research perspective, it is imperative to further focus on urban-level carbon emissions accountability. In cities, a cluster is formed by the populations, industries, and resources, making them a primary source of carbon emissions [142]. Thus, precisely delineating carbon emission responsibilities among cities can facilitate carbon reduction at the urban level. Accounting for carbon emission responsibilities in special cities is also a representative endeavor. Further, accounting for the responsibility of carbon emissions within a city cluster can provide useful insights for clarifying carbon emission responsibility and reducing carbon emissions in city clusters [143]. Investigating carbon emission responsibilities within all cities, special city clusters, and cities within these clusters can be a crucial avenue for future research.

In terms of shared carbon emission responsibility accounting, it is important to consider multiple sharing methods, rather than relying solely on the coefficient method. Using 0.5 as the coefficient for allocating carbon emission responsibility shared between producers and consumers [51,58,121] is a simple and one-sided method. Specifically, Zhu et al. discussed the carbon emission liability sharing coefficient of 0.5 [51]. Song et al., that the responsibility of producers and consumers is symmetrical, that is, producers and consumers should each bear half responsible for carbon emissions [58]. From the perspective of the benefit principle and ecological deficit, Ferng et al. calculated the carbon emission responsibility on the basis of producers and consumers [121]. It is crucial to consider alternatives to the coefficient method, which is only one of many sharing techniques available. In addition, investigating multiple sharing methods, such as diversifying burden-sharing actors and adopting scientific approaches to burden-sharing, is essential for shared responsibility accounting and represents an important direction for research. Accordingly, determining the sharing coefficient among the three is one of the key aspects of further research.

Enhancing carbon emission accountability based on the earners' principle is imperative. Studies have demonstrated that the present carbon emission responsibility guidelines emphasize only on production and consumption while overlooking the accounting of carbon emissions on the "benefit side", derived from the principle of benefit accounting [43,116,117]. However, due to the increasing specialization and differentiation of industrial labor, the production factor providers, producers, and consumers within the supply chain typically reside in different regions. To establish an all-encompassing carbon emission responsibility accounting system, a system based on income earners' principle must be implemented, and the factor supply sector should also be considered accountable for carbon emissions. Research on carbon emission transfer using the principle of returns provides insights into the import and export of emissions and their impact on revenue across different regions.

Implementing a carbon emission responsibility accounting system from the perspective of the supply chain poses yet another challenge. Because the supply chains are related to diverse trading entities, which is crucial for them to realize their economic value, carbon emission responsibility accounting cannot be handled in isolation [28,32]. Therefore, developing an approach from the supply chain's perspective is essential. Starting from the structure of the whole supply chain network and aiming at maximizing their respective values, the accounting principles based on suppliers, manufacturers, distributors, retailers, and even end users are proposed to enrich the carbon emission responsibility accounting principles and realize carbon emission responsibility accounting.

From the results of this study, it can be deduced that carbon emission responsibility accounting has a direct correlation with follow-up actions, including the fact that carbon emissions permit distribution and participation in the carbon market [144]. Carbon emission responsibility accounting has laid the basis for the reduction in carbon emissions, and its accuracy and flexibility have been pivotal to the allocation of carbon allowances [145]. With the maturation of the carbon emission trading market, it has become essential to accurately estimate carbon emission reduction responsibilities after accounting for carbon quotas, allocation methods, and principles, as well as to determine whether allocation results promote carbon neutrality goals. In addition, a fair carbon allocation method and reasonable carbon emission quotas should be established. Designating carbon compensation bases for industries implementing carbon quotas is also essential.

6. Conclusions

Carbon emission responsibility is a vital undertaking for achieving carbon reduction, as accepted in academic circles globally. Using a bibliometric analysis, this study examined the present status, development trajectory, and projected trends of 2002 English-language research samples in the Web of Science and 2087 Chinese-language research samples in the China National Knowledge Infrastructure databases.

The trajectory of current research is reflected in the following key findings. First, the number of relevant studies in the Web of Science has increased steeply after 2005. In 2010, China National Knowledge Infrastructure published the pilot study on carbon emission responsibility accounting. However, at the national level, fewer articles were published during the same period compared with Web of Science. Chinese scholars have published 32.29% of the total papers on the Web of Science platform. Second, accounting for carbon emissions entails a cross-disciplinary study. Environmental science, research on environmental matters, and green, sustainable technology constitute the primary research areas for publication in the Web of Science. Most articles in China National Knowledge Infrastructure are related to the fields of environmental science and resource utilization, trade economy, economic theory, and the history of economic thought. Research focuses in the Web of Science and China National Knowledge Infrastructure are interconnected but different. Web of Science's primary research themes include "input–output analysis", "corporate social responsibility", "climate change", "circular economy", and "industrial sectors". The literature on carbon emission responsibility accounting can be summarized into three areas, namely research perspectives, accounting principles, and accounting methods, with main research focuses being input–output analysis and implied carbon export trade. China National Knowledge Infrastructure's frontier themes encompass "carbon market", "carbon trading", and "green finance". "Environmental disclosure", "quality", "gender diversity", "carbon market", "green financing", and "carbon trading" are the new research directions for publication in the Web of Science database.

Carbon emission liability accounting has been intensively studied, especially in China. Given the dual-carbon target of China, the number of articles by Chinese scholars is expected to increase gradually, and these articles may be related to economics and trade and environmental science. The input–output data of multiple databases, such as CEADs, EXIOBASE, and WTOD, can also be used for the comparative study of carbon emission liability accounting. Regarding the principles of carbon emission responsibility accounting, this study suggests that the principle of shared responsibility should be widely used because it fully embodies the fairness aspect. Fair and reasonable accounting of the carbon emission responsibilities of all parties is indispensable for tackling global climate change. It can not only promote the fairness of global climate governance and green and low-carbon development, but also enhance the international community's awareness and action on climate change. However, researchers have not yet reached a consensus on how to design a fair and reasonable shared responsibility coefficient. Responsibility must be shared across countries, among provinces within countries, and among various departments in the industrial chain. With the development of the green supply chain, clarifying the carbon emission responsibilities of all parties involved is of utmost importance. The state has issued some policies on carbon emission liability accounting. For example, in 2021, the Chinese government issued the Comprehensive Work Plan for Energy Conservation and Emission Reduction during the 14th Five-Year Plan period. It aimed to improve the accounting methods for total emission reduction and formulate technical guidelines for accounting [146]. In 2022, the Implementation Plan on Accelerating the Establishment of a Unified and Standardized Carbon Emission Statistical Accounting System was issued [147] with the aim of establishing a unified and standardized carbon emission accounting system by 2025, thereby comprehensively improving the data quality and presenting higher requirements for the statistical accounting capacity of carbon emissions. Based on the study results, the following recommendations are made. First, the supervision of carbon emission accounting of enterprises in the industry should be strengthened. Second, the authenticity and accuracy of the accounting data must be ensured. Finally, the illegal acts of falsifying carbon accounting data and interfering with the normal operations of carbon emission statistical accounting work must be monitored and strictly penalized.

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