A Bibliometric Analysis of Carbon Finance Based on Web of Science (WOS)

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Abstract

Carbon finance and low-carbon development have received increasing attention in response to global environmental problems and economic transformation towards low carbon, but there is a relative lack of research in this area, both in domestic and abroad. Based on the WOS database, this paper uses the CiteSpace, a visual analysis tool, to analyze the number of articles published, spatial distribution and research hotspots in the field of carbon finance for a total of 31 years since 1992. Through combing through the carbon finance literature, it is found that there are three major problems with the existing literature. Firstly, the research content lacks innovation; secondly, there are few quantitative studies and the results thus lack persuasive power; thirdly, there is a shortage of macroeconomic development analysis. The future path of carbon finance research should focus on the aspects of multidisciplinary crossover-research and targeted research on models.

Keywords

Carbon Finance, CiteSpace, Knowledge Mapping, Research Progress

1. Introduction

Since peace and development are two major themes of the world, countries have been trading more frequently. The rapid development of foreign trade has brought the world together to face the challenge of rapidly increasing energy demand, and thus the challenge of energy supply has become a major bottleneck for national economic development. Economic growth, one of the four main objectives of macroeconomic policy, is in conflict with the need to reduce energy use, therefore the relationship between economic growth and energy use is a matter of ur-

gency. The environmental costs of carbon emissions from energy consumption were once borne by the public sector, but it is the private sector that produces the actual emissions from energy use. With "carbon neutrality" becoming the consensus in the world's major economies, the Paris Agreement was formally ratified by the US and China in September 2016, on the occasion of the G20 Leaders' Summit in Hangzhou. The signing of the Paris Agreement by the two major carbon emitters marked a new historical stage in global carbon emissions control. However, with the US announcing its withdrawal from the Paris Agreement in June 2017, China, the world's largest energy consumer and carbon emitter, is set to play a more important role in addressing global climate change (Wang & Wang, 2017).

With the UN's Paris Agreement on climate change implemented in 2021, more and more countries are choosing to support carbon-neutral actions to achieve their carbon reduction goals. Carbon neutrality can also accelerate the revolution in energy technology and industry. Besides, achieving peak carbon emissions is both an international commitment in global climate negotiations and a necessary option for countries to achieve structural economic transformation and sustainable development (Zou et al., 2021). In addition to the initial requirements of energy introduction, such as reforestation, reduction of energy imports, and development of new energy sources, there is also a need to reduce emissions in the process of energy use, when carbon payments, avoiding the cost of future emissions due to the loss of forests and other environmental damage, have become a high-quality solution (Luttrell et al., 2018). As a necessary part of emission reduction in energy use, carbon finance has a great significance.

Carbon finance, also known as "carbon trading", is narrowly defined as a trading and investment activity based on "carbon credits" and their derivatives, as opposed to the financial activities of the traditional financial sector. Compared to green finance, carbon finance has a narrower focus, which is primarily concerned with greenhouse gas emissions and the resulting climate change issues, and includes the trading and investment of carbon credits, carbon funds and their derivatives, low-carbon project development investment and financing, and other related financial intermediation activities (Li et al., 2022). The existing literature on carbon finance covers a wide range of industries, including forestry and automobiles.

The main contribution of this paper is to provide a chronological and spatial literature overview of the development of carbon finance and to show how it has changed and what challenges it may face in the future.

The second section reviews the main literature on the direction of carbon finance; the third section introduces the literature sources and research methods; the fourth section uses econometric tools to further analyze the volume of carbon finance publications, institutional distribution, and research hotspots; and the fifth section discusses the conclusions and outlook.

2. Literature Review

Researches on carbon finance are traced back to the 1970s, and scholars have since then applied economic tools such as trading mechanisms and taxation policies to solve the problems of resources and environment.

In terms of research direction, scholars have mainly focused on carbon trading, carbon taxation, and low-carbon energy financing. For carbon trading, most scholars have worked on the influencing factors of carbon trading (Jiang et al., 2018; Wang et al., 2019), the impact of carbon trading on various industries (Li et al., 2020; Xia et al., 2021a), and the implementation of carbon trading policies (Chen & Lin, 2021; Xia et al., 2021b). Due to the existence of factors such as price instability at the early stage of China's carbon market, Song et al. (2022) selects 15 influencing factors on carbon trading for their study to suggest a reference for the pricing mechanism of carbon trading price. Wang et al. (2022) builds a difference-in-difference model to analyze that carbon trading has a positive impact on the capital allocation efficiency of enterprises using 10 years of Chinese carbon pilot data. Lu et al. (2021) analyzes the impact of cap-and-trade and low-carbon subsidy policies on manufacturers' production and carbon emission reduction levels, and concludes that the reduction of carbon emission is affected by the price of carbon trading, independent of the unit carbon subsidy.

Researches on carbon taxes have focused on the comparison between carbon transaction taxes and other form of taxes (Chen et al., 2020; Nie et al., 2022), the impact of trade (Wang, 2020; Sheng & Wang, 2022), and the pricing of carbon taxes (An & Zhai, 2020; Zhou et al., 2020). Yu (2020) argues that interest groups exert influence on tax policy and by a two-stage game model concludes that the choice of policy differs between countries, i.e. domestic countries choosing carbon tax policies and foreign countries choosing carbon subsidy policies. Olsen et al. (2018) identifies a minimum carbon tax rate with a regulatory perspective and conducts a case study of the improved ISO New England test system, showing that the weighted and dichotomous approach can find an effective minimum tax rate. Zhang et al. (2019) uses a recursive multi-sector dynamic computable general equilibrium model to simulate the impact of a carbon tax in the US and shows that a carbon tax can lead to greater exports from China to the US and beyond.

Since the price of carbon allowances affects the efficiency of carbon market financing (Li et al., 2021), scholars have conducted a series of studies on the relationship between carbon price and financing (Li et al., 2019), as well as the related influencing factors. For example, Lu et al. (2021) compares the optimal profit and carbon reduction level under autonomous financing and concludes that manufacturers prefer to invest in carbon reduction rather than carbon quotas, while Cao et al. (2019) considers manufacturers' choice of both external and internal financing methods. The results show that investment in carbon abatement is not related to the choice of financing method, instead, it is the interest rate charged by the creditor that largely determines the financing strategy. Thus, there is a wide divergence of views among scholars on the relationship between

carbon prices and financing, and even the impacts.

3. Literature Sources and Analysis Methods

3.1. Literature Sources

In order to study the development of carbon finance since its emergence and ensure the reliability of the original data, this paper uses data of 31 years from the core databases under Web of Science (WOS) for analysis, where each piece of literature data includes title, author, abstract, keywords, references and other relevant information. The search was conducted on May 12, 2021, and the search dates covered the period of 1990-2021. In order to screen international and high-quality literature on carbon finance, the SSCI database, which includes core social science journals worldwide, was selected as the sample for literature analysis. As there are various terms related to carbon finance, "carbon finance*" was used as the subject search term, and the English language, article, and review were selected as the search terms, when setting the search criteria for the literature on carbon finance, after a comparative reading of the literature data and also referring to the article by Chen et al. (2015). A total of 923 articles were. The downloaded data were then processed by the function of Remove Duplicates, finally resulting in 889 articles from 27 years.

3.2. Analysis Methods and Tools

The visualization software adopted in this paper is CiteSpace, which is used for interactive and exploratory analysis on the development of a scientific field, visualizing the research hotspots and research directions in the field through a knowledge genealogy mapping tool (Chen et al., 2015). In this paper, the SSCI literatures in the field of carbon finance retrieved from the WOS database are analyzed in a time-phased dynamic visual mapping mainly including literature trends, core authors and institutions and keywords.

4. Characterization of the Carbon Finance Literature

4.1. Temporal Mapping

The annual distribution chart is an important indicator to measure the hotness and trend of a field or discipline over time. 889 articles on carbon finance in the WOS database were de-duplicated in CiteSpace. As the 2021 data is currently only available for the first five months, the annual distribution chart only displays the period of 1992-2020, and a total of 26 years have been studied. As can be seen from Figure 1, the literature on carbon finance as a whole has been growing year on year, from only 1 article in 1992 to 851 articles in 2020 Axel Michaelowa noted that the linkage of the EU Emissions Trading Scheme (EU ETS) with the Kyoto Protocol mechanism since 2005 has created a demand for carbon credits from private sector, which is consistent with the growth in the literature number of publications increases by an average of 7 per year since 2005, with an average growth rate of 37%.
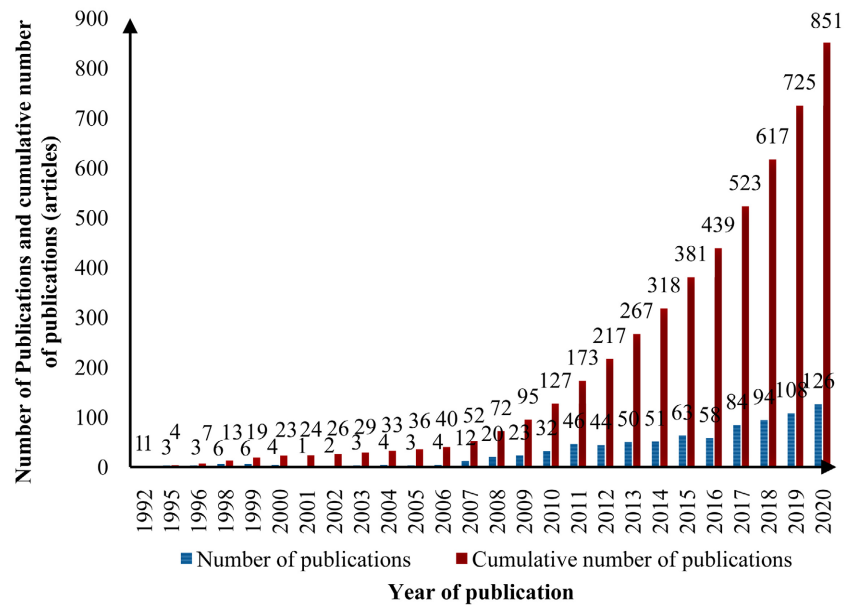
Figure 1. Number of research literatures on carbon finance based on WOS. Source: Statistics published by the WOS platform.

4.2. Spatial Distribution Mapping

4.2.1. Distribution of Authors

Setting the node type as Author, the time span as 1992-2021, the time slot as 1 year, and the G-index value as 20, a knowledge graph of carbon finance research author co-occurrence with 422 nodes, 272 connections, and a density of 0.0031 was obtained (Figure 2). It can be seen that the network of the whole mapping is more concentrated. For some of the author nodes, it shows more connections, which indicates that the distribution of the authorship in this research area is more fragmented, with a scale collaborations of a maximum of eight authors in collaborative areas and a minimum of two, however, most of the authors are independent.

According to the final statistics from CiteSpace, the total sample of 851 papers involve 422 authors. Table 1 lists 21 scholars with more than 3 publications. Among the authors, GIAMPAOLO MANZOLINI, ENNIO MACCHI, OTTMAR EDENHOFER, ANDY GOULDSON, JAN CHRISTOPH STECKEL, and MATTEO GAZZANI, are the core ones in the field, each of whom has published 6 articles related to carbon finance.

4.2.2. Institutional Distribution

The analysis of the data on the high-output research institutions in the field of carbon finance is useful to understand the authorities in the field and to have a better understanding of the current cutting-edge research findings and levels of research. As for publishing institutions (Figure 3), the University of Leeds has 20 articles, followed by the University of Oxford with 19 articles, and the University of Cambridge with 16 articles, indicating that internationally renowned universities are the main forces of carbon finance research and have achieved

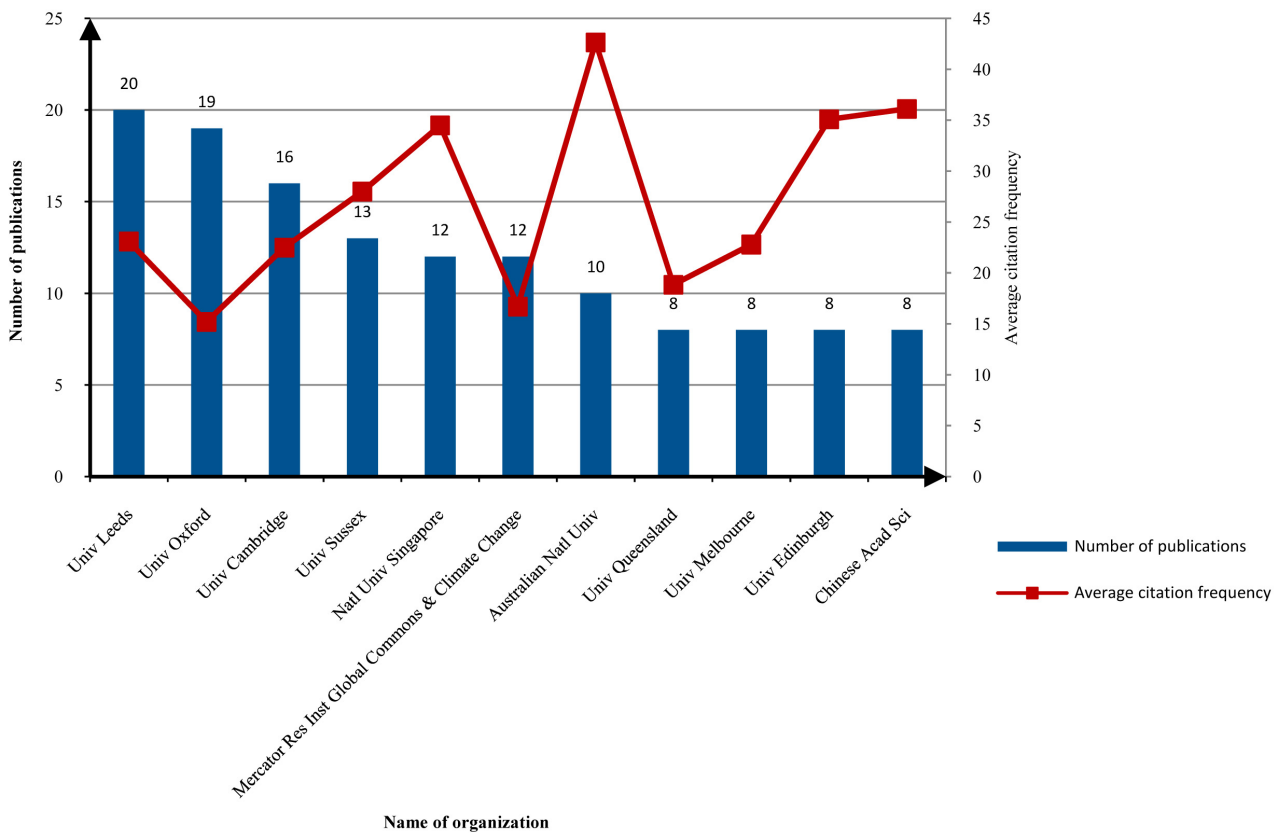**Figure 2.** Author co-occurrence spectrum. Source: Statistics published by the WOS platform.

Figure 3. Research institutions and citation frequencies. Source: Statistics published by the WOS platform.

fruitful accomplishments. In terms of citations, the Australian National University has the highest average of 42 citations, while the Chinese Academy of Sciences and the National University of Singapore rank the second and the third, with 36 and 34 citations, respectively.

4.3. Carbon Finance Research Hotspots

4.3.1. Visual Analysis of Co-Occurring Keywords in Carbon Finance

A research hotspot is an intrinsically linked group of research questions or topics that are addressed in a large number of papers over a period of time. The keywords are the high level of brevity and summary of the core content of the article. From Figure 4, it can be seen that climate change, policy, finance, carbon emissions, energy, impact, CO_2 emissions, renewable energy, China, and governance are the most frequently used keywords in the data of 27 years from 1992 to 2021. The node centrality of climate change, policy, and finance exceeds 0.1, and the frequencies of these words are 135, 100 and 92, respectively.

4.3.2. Clustering Analysis of Co-Occurring Keywords in Carbon Finance Research

After keyword co-occurrence analysis, similar keywords and words with relatively consistent frequencies are placed together and sorted by the CiteSpace software to form clusters that reflect the hot issues in a certain research field and generate keyword clustering knowledge maps (Figure 5).
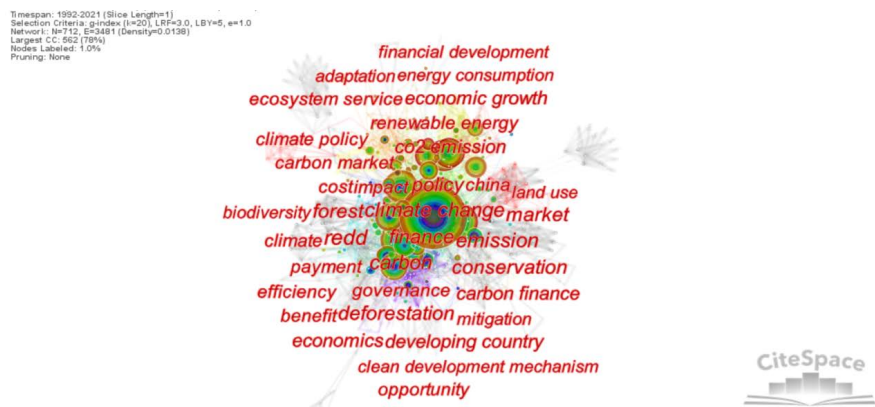

Figure 4. Keyword co-occurrence map in the field of carbon finance research. Source: Statistics published by the WOS platform.

Table 1. Carbon finance core authors and the number of their publications.

Author	Number of publications
GIAMPAOLO MANZOLINI, ENNIO MACCHI, OTTMAR EDENHOFER, ANDY GOULDSON, JAN CHRISTOPH STECKEL, MATTEO GAZZANI	6
ALEX Y LO	5
MICHAEL JAKOB, JEANCHARLES HOURCADE, IRENE MONASTEROLO, BENJAMIN S THOMPSON	4
KAI LESSMANN, ANNELA ANGERKRAAVI, F TRIEB, BRIGITTE NERLICH, ANDREW SUDMANT, EDWARD L WEBB, ANTHONY PATT, ALEX BOWEN, LH GOULDER, ANNA GEDDES	6

Source: Statistics published by the WOS platform.

From the 853 articles studied, the top 8 ones are selected for clustering: financial development, clean development mechanisms, organic carbon stocks, economic growth, low carbon cities, multiple roles, financial constraint, and a prototype clean development mechanism. This is in line with the research hotspots identified in the literature (Table 2).
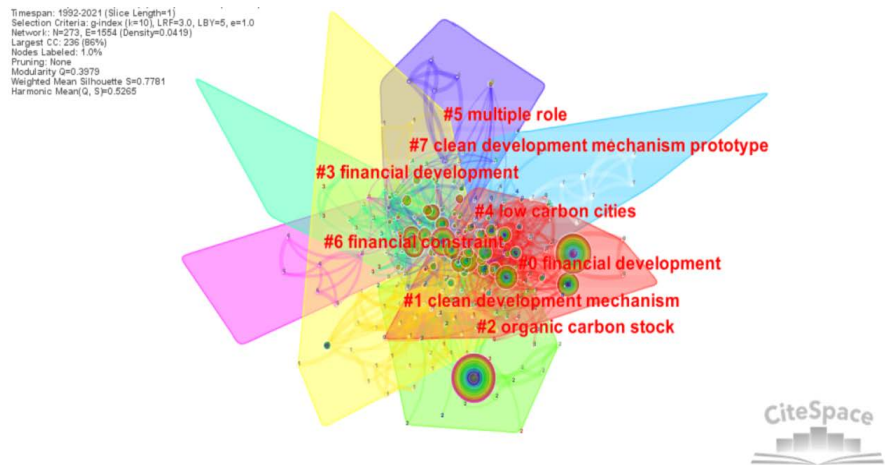

Figure 5. Keyword clustering maps of carbon finance. Source: Statistics published by WOS platform.

Table 2. Carbon finance keyword co-occurrence network clustering table.

Cluster number	Size of cluster	Identifying words (Select the first 5)
0	55	Financial development; biodiversity co-benefit; blue carbon; carbon-biodiversity trade-off; risky business
1	42	East Asia; carbon Taxes; national development; carbon trading; effective Redd architecture
2	31	Organic carbon stock; Paris agreement; emerging cook stove carbon market; non-temperate area; cook stove project
3	30	Economic growth; financial development; energy consumption; environmental degradation; carbon emission
4	27	Low carbon cities; sustainable development goal; carbon capture; low-carbon city; local government leverage
5	23	Multiple role; state investment bank; low-carbon energy finance; energy finance; adaptive market
6	16	Financial constraint; yield uncertainty; ordering quantity; incorporating risk aversion; capital-constrained supply chain
7	8	Clean development mechanism prototype; forest protection; cost Arica; financial development; carbon finance

Source: Statistics published by the WOS platform.

5. Conclusion and Prospect

This paper compares previous research on carbon finance and systematically analyzes the relevant literature. The CiteSpace metering software is used to visualize and analyze the volume of journal publications, major authors, research institutions, and research hotspots. The following conclusions are drawn: 1) in the temporal distribution, the literature on carbon finance is relatively rare and underdeveloped before 2009, but the number of journal articles increases exponentially after that. 2) In the spatial distribution, it is shown that the research group on carbon finance has not formed a stable core group of authors but mainly exists in the form of independent research. 3) In terms of research hotspots, carbon trading has become a key topic in this field. Research hotspots include carbon taxation, carbon trading risks, supply chains, and low-carbon financing.

Due to the late start of the research on carbon finance, it is still in the development phase. The existing research findings of scholars on carbon finance vary greatly and are mostly focused on the research on carbon finance trading mechanisms and pricing, while few scholars have analyzed the overall development of carbon finance in a macroeconomic context. Due to the difficulties in the access to data, there is a lack of quantitative research literature, which leads to little comprehensive analysis and systematic assessment.

As the country has gradually paid attention to the economic transformation and the development of carbon finance, the aspects for future research are proposed. 1) Consideration should be given to developing carbon finance mechanisms while summarizing the current situation and the shortcomings of macroeconomic development. 2) Carbon finance research should combine qualitative and quantitative analysis, and quantitative development can greatly promote further development of the practice. 3) In a current a period of the rapid development of information technology, carbon finance should be combined with big data and the Internet of Things accordingly, thus providing technical support for better service development of carbon finance.

The flourishing carbon finance market should be supported by corresponding policies, and future policies should consider the following aspects. 1) Developing multi-level products aims to help different enterprises. At present, the development of carbon products mainly involves spot market, with less development for carbon bonds and corresponding derivative products. 2) Strengthening the supervision and market regulation of the carbon finance market should also be the policy target. For fundraisers to raise funds in accordance with the information disclosure system, strict control of the relevant processes is necessary.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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