energies

Review

A Scientometric Analysis and Review of the Emissions Trading System

Yu-Jie Hu [1,2,*], Lishan Yang [1], Fali Duan [2], Honglei Wang [1,3] and Chengjiang Li [1,4]

[1] School of Management, Guizhou University, Guiyang 550025, China; yanglishanyls@163.com (L.Y.); hlwang@gzu.edu.cn (H.W.); chengjiang.li@utas.edu.au (C.L.)
[2] State Key Laboratory of Public Big Data, Guizhou University, Guiyang 550025, China; faliduan@163.com
[3] Key Laboratory of "Internet+" Collaborative Intelligent Manufacturing in Guizhou Provence, Guiyang 550025, China
[4] School of Engineering, University of Tasmania, Hobart, TAS 7005, Australia
* Correspondence: yjhu@gzu.edu.cn

Abstract: As a vital market mechanism to mitigate global warming, the emissions trading system (ETS) has critical research and practice value. According to articles from Web of Science's core collection, quantitative statistics are used to analyze the ETS, including statistics on the number of articles, distributions of time and geography, journals and subjects, productive authors and institutions, academic collation, article citations, and hot topics. Moreover, this paper presents a qualitative analysis of research on the ETS, exploring hot issues, including its origin, allowance allocation, the impact of allowance allocation, and the ETS in the power sector. The results show that it is necessary to launch ETS to mitigate climate change effectively and reduce emissions at a low cost. Allowance allocation as its critical component has also caused heated discussion among scholars. In allowance allocation, exploring a desire to assign the future allowable carbon emissions reasonably and efficiently is vital, yet scholars widely do not accept this. Moreover, free allocation can only be applied to the transitional stage, and auctioning will be inevitable. In addition, scholars have studied the impact of different allowance allocation schemes from macro and micro perspectives and take the power sector, namely the largest emitter, as an example, by linear programming, equilibrium modeling, and multi-agent modeling. However, the quota allocation scheme needs improvement due to firms' accuracy of emission data. Finally, governments are encouraged to launch the ETS to reduce emissions and combat climate change. The ETS should be improved gradually, including aspects such as cap setting, covering sectors, and the allocation method. Additionally, some key emission sectors and regions can be taken as the research and practice objects in the initial stage of the ETS.

Keywords: emissions trading system; allowance allocation; quantitative statistics; qualitative analysis

Citation: Hu, Y.-J.; Yang, L.; Duan, F.; Wang, H.; Li, C. A Scientometric Analysis and Review of the Emissions Trading System. *Energies* **2022**, *15*, 4423. https://doi.org/10.3390/en15124423

Academic Editor: V. Indra Gandhi

Received: 19 May 2022
Accepted: 14 June 2022
Published: 17 June 2022

1. Introduction

Global greenhouse gas (GHG) emissions continued to rise until 2019; the aggregate reductions suggested by the current nationally determined contributions (NDCs) until the year 2030 would still make it impossible to limit warming to 1.5 °C with no or limited overshoot [1]. Therefore, it is necessary to take more ambitious mitigation actions to limit warming to 1.5 °C while achieving sustainable development and poverty eradication. The Kyoto Protocol proposes the three flexible mechanisms of "joint implementation (JI)", the "Clean Development Mechanism (CDM)", and the "emissions trading system (ETS)" to help developed countries and countries with economies in transition achieve their emission reduction targets. Moreover, as an essential market mechanism to mitigate global warming, deal with climate change, and promote green development, the ETS has become the focus of international attention in the past 20 years and has profoundly impacted the global economy and industrial structure in the 21st century. In 2021, the number of emissions regulated by the emissions trading system increased to three times that of 2005, by nearly

17%, and the GDP of the jurisdictions that established the ETS accounted for 55% of that figure [2].

The carbon emissions trading system can be traced back to Ronald Coase [3], who argued that under certain conditions, the externalities or inefficiencies of the economy could be corrected through negotiation by parties, thus achieving the maximization of social benefits. Based on this idea, J.H. Dales put forward the idea of an emissions trading system. In the early 1970s, Montgomery rigorously proved that the emissions trading system is characterized by controlling pollution at an efficient cost, i.e., it requires the minimum price to achieve pollution control objectives. Accordingly, various types of emissions trading systems, including carbon emissions, are beginning to be widely launched worldwide. Therefore, it is necessary to research the emissions trading system, systematically analyze its research progress, work on, and solve scientific and technological problems that need to be solved, and promote the healthy development of the carbon trading system, which facilitates the realization of national emission reduction targets.

Regarding the systematic and quantitative literature analysis, the bibliometric method has been widely used to assess the performance of various disciplines [4,5]. Focusing on the topic of economic, energy, and climate policy, Kiriyama et al. used the bibliometric method to illustrate an overview of trends in nuclear energy technology and related fields [6]. Wei et al. utilized the bibliometric method to summarize the important research topics and methodologies in the field of climate policy modeling based on the SCIE and SSCI datasets [7]. Yu et al. applied the bibliometric method to analyze the scientific publications on low-carbon energy technology investment [8]. Zhang et al. used the bibliometric method to characterize the carbon tax literature from 1989 to 2014 [9]. In terms of research on the ETS, Wang and Tang used the bibliometric method to analyze comparative studies on different market mechanisms applied to carbon reduction between 1970 and 2016 [10]. Ji et al. used the bibliometric method to analyze the characteristics of the most relevant studies of carbon prices in emissions trading schemes [11]. Tang et al. presented a comprehensive literature review on full-scale types of quantitative models in the research on emissions trading systems [12]. Unlike previous research, this study, using a bibliometric method and combining in-depth qualitative analysis, offers a comprehensive and systematic literature review on the ETS, including its origin, core mechanism, and research hotspots. This study points out the practical problems and research gaps in the ETS.

All in all, this research on the ETS has great practical guiding significance and value. This study focuses on the in-depth quantitative statistics and qualitative analysis of research on the ETS in general and finds the research hotspots in the ETS. This study draws on ETS research, including its origin, core mechanism, research hotspot, and impact. This paper attempts to provide an effective guarantee for improving ETS mechanism construction, promoting emission reduction, and mitigating climate change through a comprehensive scientific review.

2. Materials and Methodology

The data are from Web of Science's core collection, including the Science Citation Index Expanded (SCIE, 1990–present) and the Social Sciences Citation Index (SSCI, 1981–present). A total of 2726 articles containing topics (titles, keywords, and abstracts) about the "emission trading system" were obtained on 6 April 2022. The number of articles published in different years and regions and the research hot spots comprise the quantitative statistics. A total of 832 articles were gained whose topics were "emission trading system" and "allowance allocation". As for the articles, on the one hand, quantitative statistics were used to analyze them in terms of factors such as the number of pieces, distributions of time and geography, the journal and subject, productive authors and institutions, academic collation, article citations, and hot topics. On the other hand, in this paper, we performed a qualitative analysis of research on the ETS, exploring hot topics, allowance allocation, the impact of allowance allocation, and the ETS in the power sector.

2.1. Quantitative Statistic

Based on the articles obtained, this study applied indicators such as the h index, impact factor, citation frequency, co-operation degree, and other indicators to evaluate the scientific output of the ETS comprehensively.

The h index is a mixed quantitative indicator that can be used to assess the amount of academic output and the academic output levels of researchers. The h index was proposed by Hirsch (2005). He indicated that when a scholar's h-many papers are cited at least h times, and the remaining (N-h)-many papers are not cited more than h times, then the scholar's h index is h. The impact factor (IF) refers to the data from the Journal Citation Reports (JCR) produced by Thomson Reuters. It was devised by Eugene Garfield, the Institute for Scientific Information founder. It means that the total number of citations for papers published in the first two years of a journal in the year of the report (JCR year) is divided by the total number of papers published by the journal in the two years. This is an internationally accepted evaluation indicator for journals. Citation frequency is the number of times an article is cited in the statistics year. It is an important indicator that reflects the influence of the paper, which is directly obtained by the WoS data platform. The total citation frequency is the sum of citations for a given number of papers, and the average citation frequency is the average number of citations for each article. The co-operation degree indicator measures international partnerships in a research area, indicating the amount of co-authoring or co-citing. This study explored the co-operation between productive authors and institutions.

In addition, this study used the Bibexcel software to analyze the keywords in all the literature in the field and to find research hotspots and future development trends using word frequency analysis on the keywords.

2.2. Qualitative Analysis

In this paper, we also performed a qualitative analysis of the research hotspots from quantitative statistics. We adopted the method of classifying topics and comparing methodology. We conducted an in-depth literature review on the dimensions of research problems, techniques, and specific empirical evidence.

In terms of the ETS, this paper explored why the ETS should be launched and focused on the critical issue of the ETS, i.e., allowance allocation. Moreover, this paper discussed the research on the methods and principles of the ETS and tried to find which scheme is the best for allowance allocation. In addition, scholars also care about the impacts of the ETS or its allowance allocation. They have conducted qualitative and quantitative analyses from macro and micro perspectives to study the implications of different allowance allocation schemes. They consistently choose the power industry for empirical research. Therefore, this paper compared the methodology used by these studies and tried to find a more appropriate method.

3. Quantitative Statistics Results

3.1. Research Hotspots on ETS Research: Allowance Allocation

Based on the 2726 articles obtained whose topics were related to the "emission trading system", this paper analyzed their frequency of keywords and clustered them. This clustering indicated that most articles focus on the EU ETS, China's ETS, climate change, climate policy, transaction costs, tradable permits, allocation, national allocation plans, burden sharing, grandfathering, auctioning, and so on (as shown in Figure 1). Therefore, in this paper, quantitative statistics on the issue of allowance allocation is conducted.

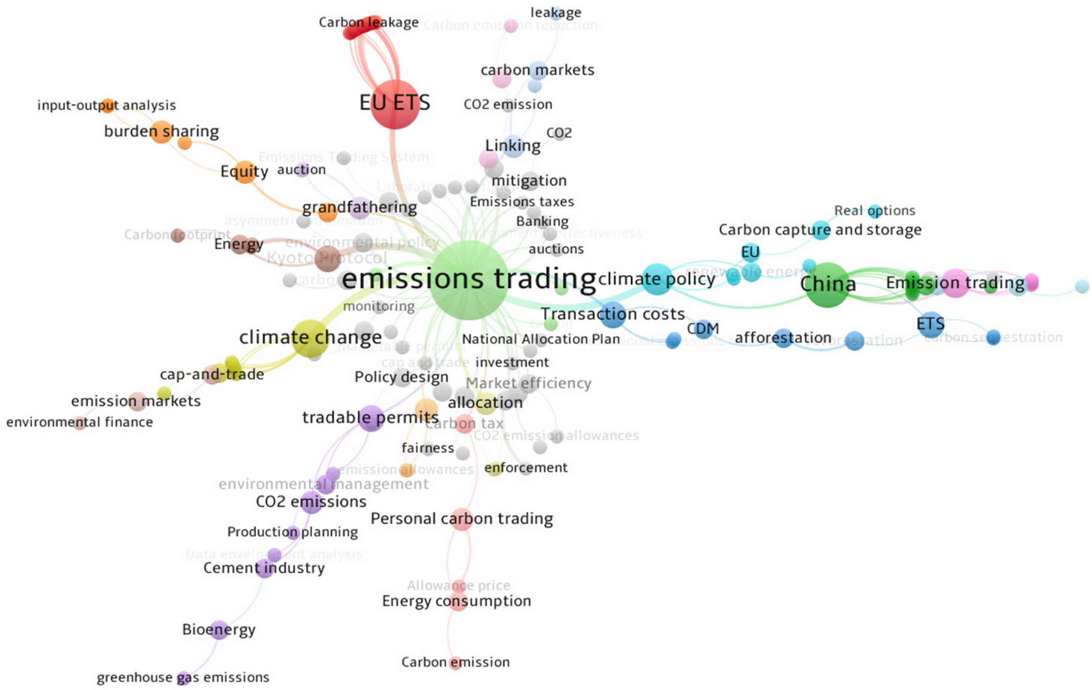

Figure 1. The frequency of keywords: research hotspots.

3.2. Productive Subjects of Research on Allowance Allocation

A total of 832 articles on the topics of the "emission trading system" and "allowance allocation" were selected. According to the ten productive subjects listed (as shown in Table 1), research on allowance allocation is interdisciplinary, referring to the environment, economics, energy fuel, engineering, chemistry, management, and so on. Most subjects are environmental studies, environmental sciences, economics, and studies related to energy fuel. Environmental studies are the most popular, with 318 publications on allowance allocation, accounting for 38.22% of the total studies, and environmental sciences and economics, accounting for 34.38% and 34.26% of the full records, respectively.

Table 1. Productive subjects.

Subjects	Publications	Percentage
Environmental Studies	318	38.22%
Environmental Sciences	286	34.38%
Economics	285	34.26%
Energy Fuels	205	24.64%
Green Sustainable Science Technology	126	15.14%
Environmental Engineering	77	9.26%
Public Administration	76	9.14%
Chemical Engineering	37	4.45%
Operations Research/Management Science	22	2.64%
Business	21	2.52%

3.3. The Amount and Distribution of Publications on Allowance Allocation

It can be seen from Figure 2 that the number of publications on allowance allocation increased from 1 (1995) to 110 (2021). The number of publications showed an overall upward trend.

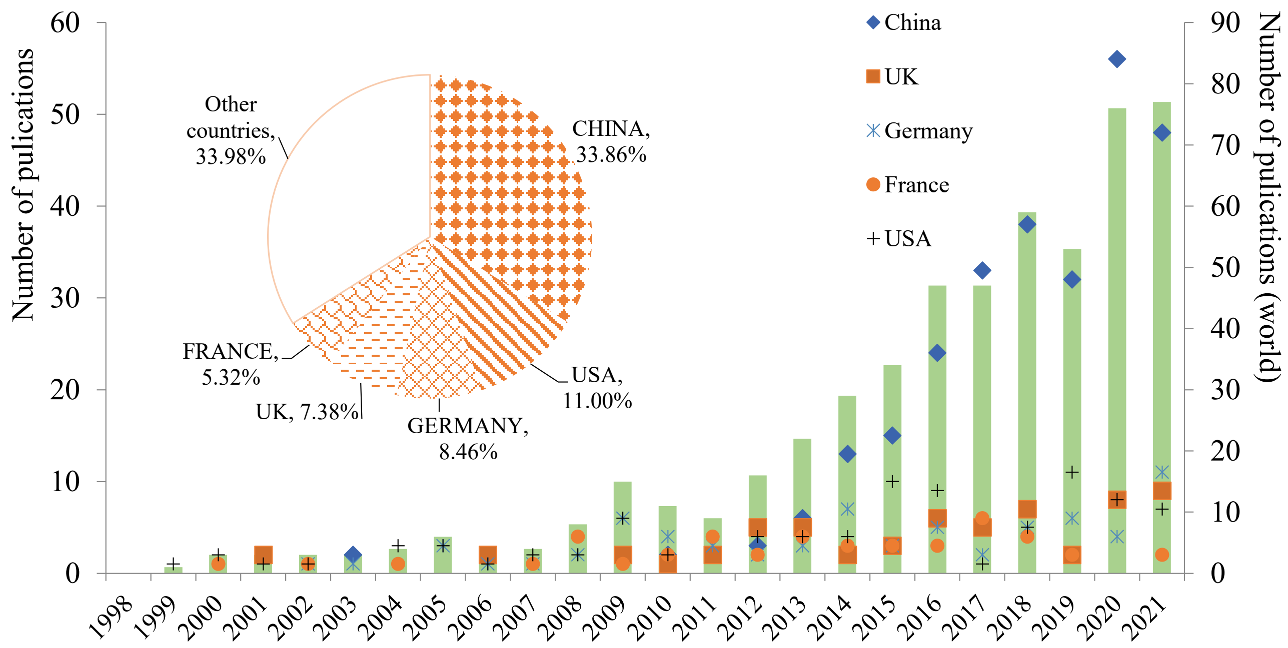

Figure 2. Timeline and percentages of publications in producing countries.

Journal distribution and the impact thereof has been a popular field research area. The world's top articles in this field are mainly concentrated in China, North America, Europe, and Australia. With further analysis, the top five productive countries in this area are listed as China, the United States of America, Germany, the United Kingdom, and France. The proportion of articles written by researchers from these countries has reached 66.02%. Since 2013, when China began to launch the ETS pilots, the number of publications from China has shown a rapidly increasing trend, and the number of publications from China has surpassed those from the United States, the United Kingdom, and Germany. It is seen that with the strong determination of China to launch the ETS, academic circles have had heated discussions on this topic, and they are trying to work out an effective and theoretically instructive allowance allocation scheme that is more suitable for China's national conditions, which is a very realistic and theoretical research direction.

Table 2 shows that 832 publications on ETS's allowance allocation (accounting for 45% of the total articles on this topic) are included in the top ten journals in the research fields of climate change, energy and the environment, and the economy. Their impact factor is about 2.8 to 12.5, indicating that these studies have decisive academic importance in these fields. Among the articles, 70 articles that were cited 2680 times were published in Energy Policy, whose impact factor in 2021 was 5.354 and whose h index was 30, followed by The Journal of Cleaner Production and Energy Economics, with impact factors of 7.646 and 7.042 in 2021, and which contained 66 articles cited 1554 times and 51 articles cited 1927 times, respectively. These are the three most famous journals. Moreover, Renewable and Sustainable Energy Reviews and Applied Energy are the most influential journals, with 13 articles cited 464 times and 33 articles cited 1334 times, respectively.

Table 2. Journal distribution.

Journal	2021 Impact Factor	Average Citations	h Index
Energy Policy	5.354	38.29	30
Journal of Cleaner Production	7.646	23.55	24
Energy Economics	7.042	37.78	23
Applied Energy	9.007	40.42	22
Climate Policy	5.085	21.63	22
Ecological Economics	4.718	45.36	9
Sustainability	2.806	7.71	9
Energy	6.255	32.08	9
Renewable and Sustainable Energy Reviews	12.549	35.69	8
Journal of Environmental Economics and Management	4.624	14.69	8

3.4. Productive Authors and Institutions and the Co-Operation between Them

3.4.1. Productive Authors and the Co-Operation between Them

These articles were written by 1839 authors. As shown in Table 3, the top 15 most productive authors studying allowance allocation are from different countries, mainly from the USA, China, and Germany. China, as the only developing country among them, has active scholars in the field of ETS and allowance allocation and has put mitigating actions into practice. The top 15 most productive authors have published 11 articles that were cited 338 times on average. Bohringer C, Wei YM, and Chevallier J published 16, 19, and 19 articles that were cited 478, 615, and 541 times, respectively, and which have more oversized h indexes, i.e., 13, 11, and 10, respectively. Wei YM is 2021's most cited Chinese researcher in the energy economy and climate change field, and they are from the Beijing Institute of Technology. Although Ellerman AD, Neuhoff K, and Quirion P published less, they are cited more, resulting in a more significant number of average citations per article, i.e., 67.30, 59.88, and 45.63 with h indexes of 8, 7, and 7, respectively.

Table 3. The top 15 most productive authors.

Authors	Average Citations per Article	h Index	Country
Bohringer C	29.88	13	Germany
Wei YM	32.37	11	China
Chevallier J	28.47	10	France
Loschel A	25.50	9	Germany
Den Elzen MGJ	30.67	9	Netherlands
Burtraw D	29.50	9	USA
Ellerman AD	67.30	8	USA
Stranlund JK	16.67	8	USA
Zhang ZX	17.88	7	China
Jotzo F	29.13	7	Australia
Fan Y	14.54	7	China
Quirion P	45.63	7	France
Neuhoff K	59.88	7	Germany
Cason TN	33.71	7	USA
Wettestad J	13.71	6	Norway

This paper analyzed the co-operation between productive authors with seven or more publications on this topic. As shown in Figure 3, there are many relationships between them, and Wei YM, Loschel A. Fan Y, and Neuhoff K are the most active. Firstly, Wei YM and Chevallier J discussed the ETS and carbon prices together. Wei YM and Den Elzen MGJ explored the economic and energy implications for China and India in an international climate regime. In addition, there is some co-operation between Wei YM and Tang BJ, and Peterson S and Zhang YJ. Chevallier J and Quirion P also discussed carbon prices. Secondly, Loschel A and Bohringer C assessed emission regulations in Europe. They explored how US withdrawal has consequences on environmental effectiveness, compliance costs, and excess costs of market power under the Kyoto Protocol. Loschel A and Jotzo F published the study Emissions trading in China: Emerging experiences and international lessons. Loschel A and Zhang ZX discussed the economic and environmental implications of the US repudiation of the Kyoto Protocol and the subsequent deals in Bonn and Marrakech. Thirdly, Fan Y, Zhu L, and Wang X explored how China can achieve the emission reduction target and China's ETS. Finally, Neuhoff K and Grubb M discussed the EU ETS allocation plans and their implications. In addition, Fan J, Wang SY, and Li J from the University of Science and Technology of China explored the importance of a personal carbon trading scheme. Moreover, Liu Y, Ozturk I., and Lin BQ have been committed to the extent of mitigation mechanisms.

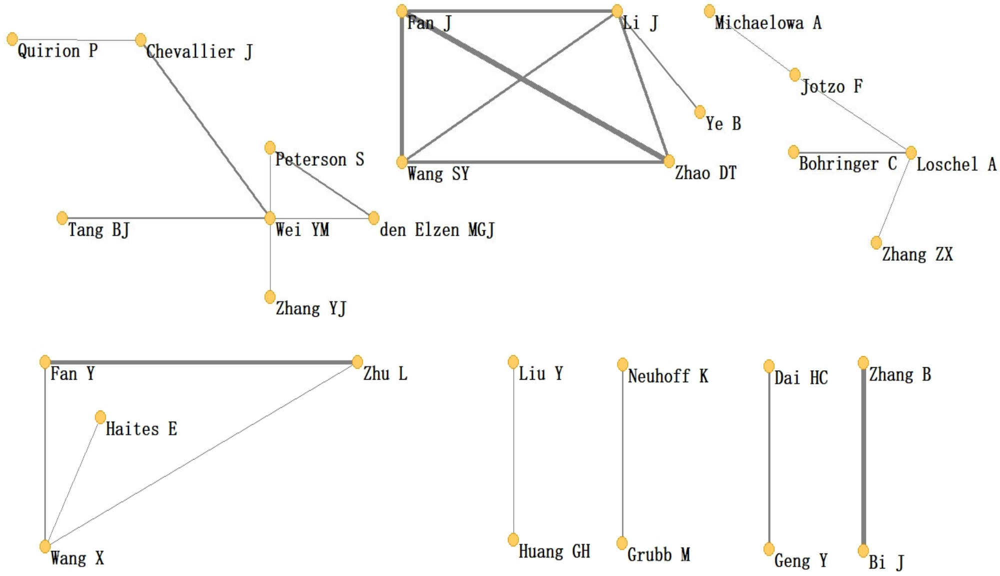

Figure 3. Co-operation among productive authors.

As a whole, there is much co-operation between productive authors, which is conducive to us scientifically solving the problem of allowance allocation in China's construction of its own ETS. In terms of bibliographic coupling by authors (as shown in Figure 4), it can be seen that there are many connections between the scholars' research on allowance allocation. Chevallier J, Peterson S, and Fan Y have cited many of the same references. Chevallier J, Wei YM, Wang K, and Zhang YJ have cited many of the same references. Additionally, Wei YM, Ye B, and Wu R have cited many of the same references. This indicates that there is a solid academic relevance in the research on China's ETS, and scholars continue to exchange ideas and realize the process of development in the study of issues concerning the ETS.

3.4.2. Productive Institutions and Co-Operation between them

The authors are from 1192 different research institutions around the world. The top 15 most productive institutions are shown in Table 4. Among them, MIT, Cambridge University, Harvard University, and Resources for the Future are world-class and famous and have rich research resources and experience to ensure the smooth realization of scientific research (according to QS World University Rankings, Times Higher Education, and RePEc/IDEAS Ranking). The institutions are in different countries, most of which are in the USA and Germany, some of which are in developed countries trying to transform, and China, a developing country trying to avoid significant emissions. Therefore, this research is vital for them. The top 15 most productive institutions have published 19 articles that were cited 435 times on average. Among them, the Beijing Institute of Technology, MIT, and Cambridge University published 33, 25, and 18 articles that were cited 786, 905, and 887 times, with relatively extensive h indexes of 15, 13, and 12, respectively. In addition, although Harvard University and Massachusetts University published less, they are cited more, resulting in a more significant number of average citations per article, i.e., 40 and 31, respectively, with h indexes of 9.

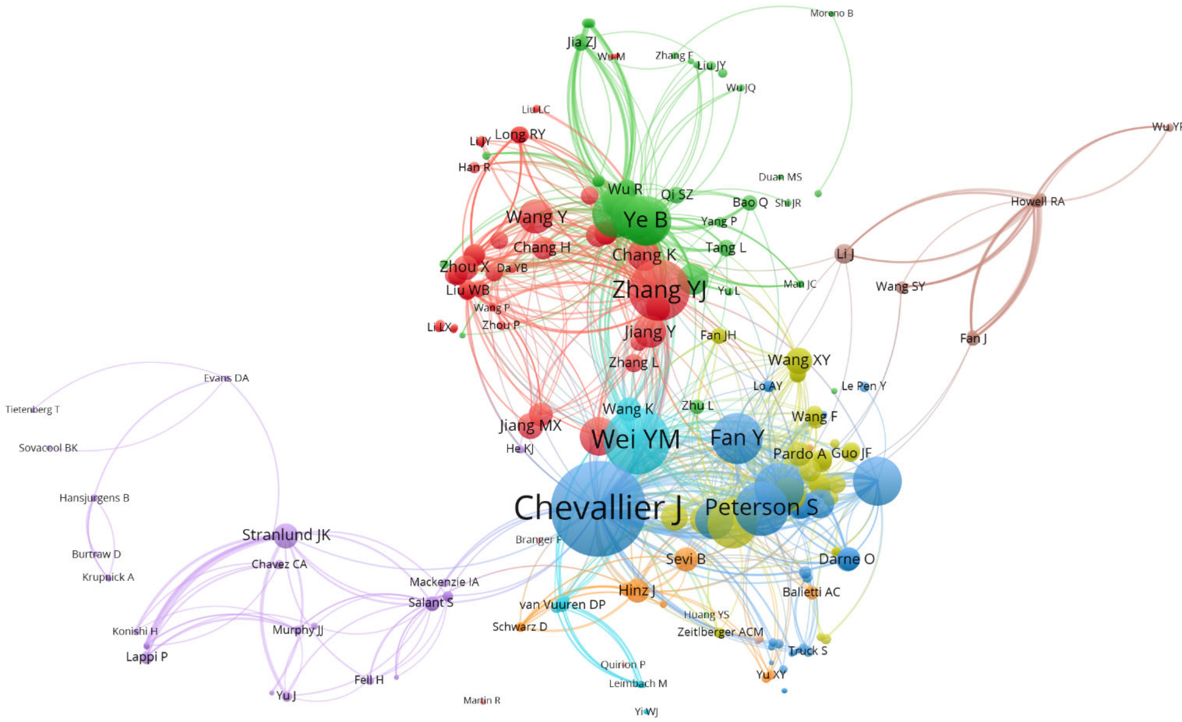

Figure 4. Bibliographic coupling by authors.

This paper also analyzed the co-operation between institutions. It can be seen that there are many connections between productive institutions (as shown in Figure 5). The Beijing Institute of Technology has a certain level of co-operation with Hunan University and Nanjing University. Tsinghua University co-operates with Nanjing University, National Singapore, MIT, and Duke University. The Chinese Academy of Sciences co-operates with Wuhan University, Shanghai Jiao Tong University, and Beihang University. In addition, there are many connections between University College Dublin, Cambridge University, Harvard University, MIT, and ZEW. In general, university alliances or co-operation has dramatically promoted the resolution of scientific problems regarding the ETS.

Table 4. The top 15 productive institutions.

Institutions	All Articles	All Citations	h Index	Country
Beijing Inst. Technol.	33	786	15	China
MIT	25	905	13	USA
Univ. Cambridge	18	887	12	UK
Chinese Acad. Sci.	39	635	12	China
Potsdam Inst. Climate Impact Res.	14	291	10	Germany
Univ. Maryland	14	349	10	USA
Ctr. European Econ. Res. ZEW	19	387	10	Germany
Tsinghua Univ.	31	260	10	China
Univ. Paris 09	12	211	9	France
Harvard Univ.	9	357	9	USA
ETH	13	277	9	Switzerland
Univ. Massachusetts	12	373	9	USA
Univ. Groningen	15	190	9	Netherlands
Resources Future Inc.	13	256	9	USA
Univ. Coll. Dublin	14	366	9	Ireland

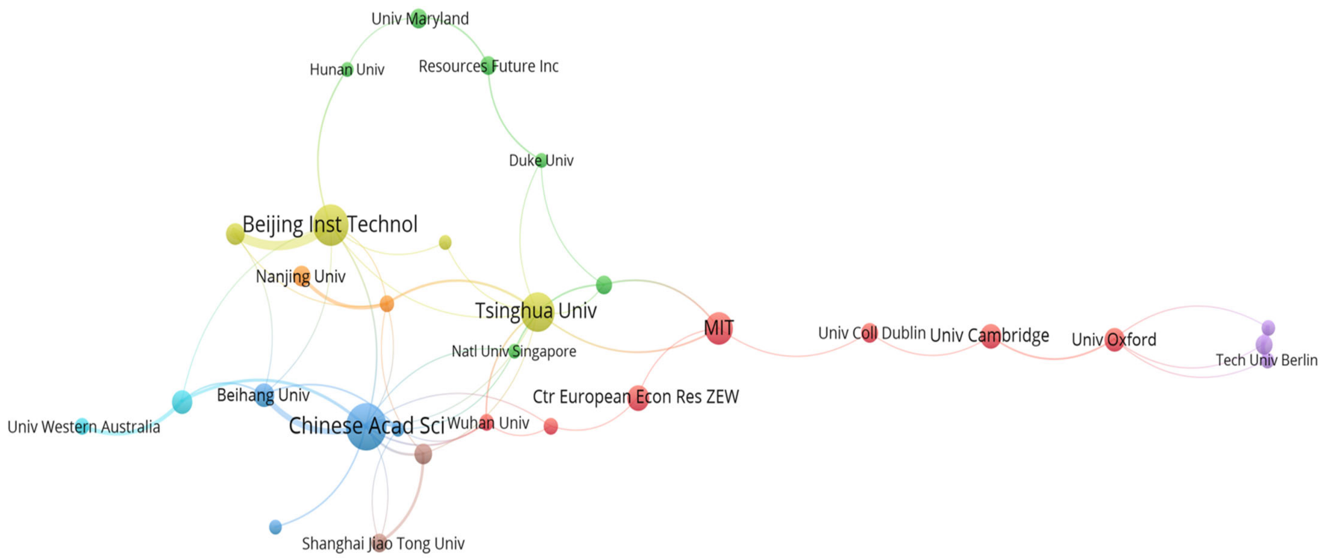

Figure 5. Co-operation of institutions.

4. Research Hotspots

This paper analyzed word frequency via the induction of all the keywords, titles, and abstracts in the retrieved 1991–2021 research literature on the ETS, and the research hotspots are drawn as follows: emissions trading, carbon, allocation, energy, power, China, European, market, policy, cost, and model (as shown in Figures 6 and 7). Therefore, it is necessary to research climate change mitigation using an effective climate policy, i.e., the emission trading scheme, which has been well developed in the European Union and has just been launched in China, and allowance allocation. Additionally, multi-objective optimization, data envelopment analysis, game theory, and input–output analysis are the most used methods.

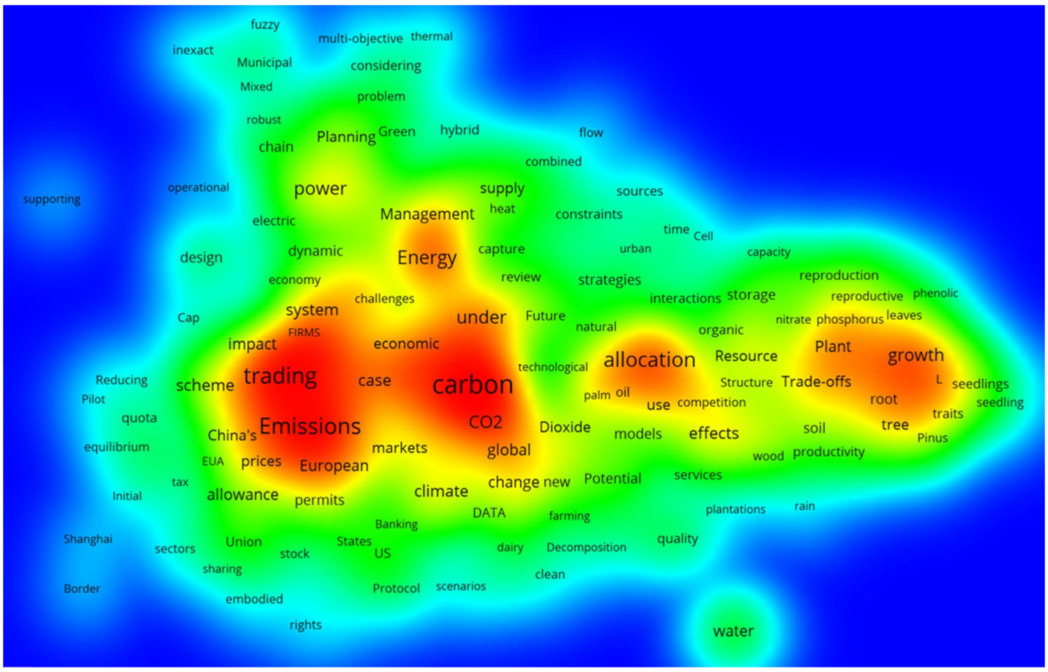

Figure 6. Thermal map of title word density.

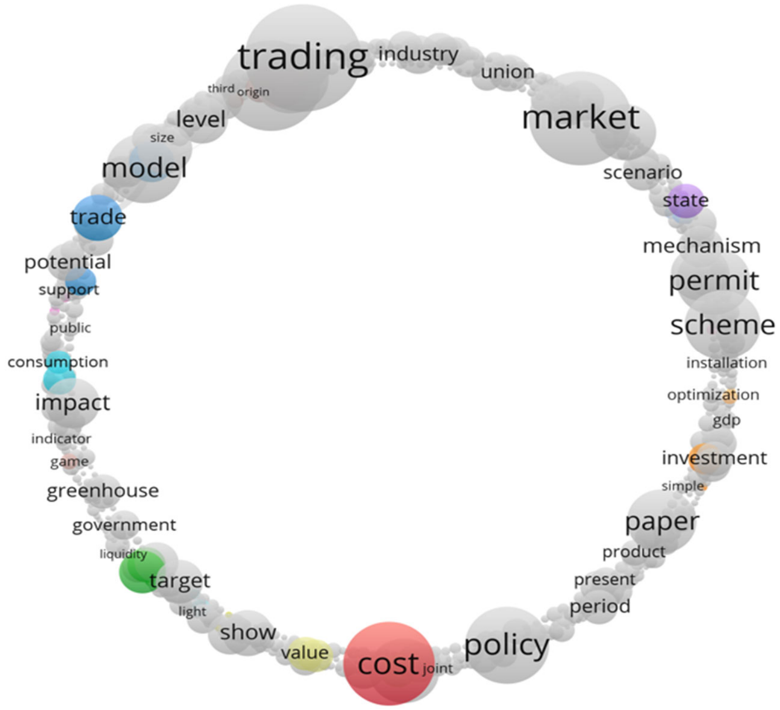

Figure 7. Words that appear more than ten times in the abstracts.

As for the power sector, it frequently appears 1007 times ("power" and "electricity"), and scholars focus on the impacts of the ETS and allocation allowance plans on the power sector: evidence from the power sector, including effects on the electricity market (electricity demand, enterprises, and price), investment decisions, electrical technology (generation, supply system, and transmission), electricity planning, and so on.

Therefore, this paper focused on three research hotspots in the field. They are: Why should ETS be launched? What is a better allowance allocation plan? What are the implications of the ETS and its allowance allocation, and what evidence exists from the power sector?

4.1. Carbon Emissions Trading System Has Cost Effects and Comparative Advantages

Scholars have recently had heated discussions on achieving national emission reductions. They compared the quantitative mechanism or the command-and-control regulation of emission reductions, namely the ETS, as a typical representative, with price incentives, namely carbon tax, as a typical representative. Additionally, they found that the ETS can achieve more significant environmental benefits at a lower cost and has comparative advantages. Hepburnexamined the relative advantages of price, quantity, and hybrid instruments according to the efficiency, trade-off, implementation, international considerations, and political economy [13]. Weitzman used the relative slope decision-making criterion (RSDC) to compare the social welfare of quantity and price regulation under uncertainty, significantly contributing to the emission reduction mechanisms' comparison [14,15].

Given the research on costs and benefits, researchers praise taxation policies for their abatement benefits. Pearce showed that the carbon tax not only improves the environmental quality but also offsets the income from carbon tax against other corporate taxes, increases employment and investment, and makes the economy more efficient [16]. Lin and Jia indicated that the tax mechanism is easier to understand and implement than the total amount control [17]. Gao pointed out that although the ETS's emission reduction effect is better than the carbon tax policy in the short term, the emission reduction potential for a carbon tax is more significant in the long run, and the emission reduction cost is also lower than the ETS [18]. Jia and Lin pointed out that in the long run, the emission reduction capacity of the carbon tax is slightly greater than that of the carbon trading mechanism [19].

Harstad et al. indicated the price agreement dominates the quantity agreement because when firms are free to modify the investment levels of another government defect, the punishment for defection is more substantial [20].

However, the advantages of quantity policies are increasingly prominent. Tang, Wang, and Wei found that quantity regulation results in learning how to eliminate cost uncertainty endogenously [21]. On the one hand, it can achieve more significant environmental benefits at a lower cost. Zhao et al. indicated a carbon emissions policy harms the economy. Compared to a carbon tax, a carbon trading scheme has a relatively slight impact on the economy [22]. Blackman et al. indicated that market-based policies are believed to be more effective in achieving the minimum cost of compliance and alleviating information asymmetry [23]. Wei showed it is difficult to control pollution using "command-control" regulations at the lowest price since technological innovation has insufficient incentives to eliminate and reduce pollution. Instead, Wei argued that market-oriented governance is more flexible [24]. Soto proposed using market mechanisms to solve environmental problems. The emissions trading system under total control shows that the cost of achieving emission reduction between different pollution sources is additional [25].

On the other hand, the carbon emissions trading system also has comparative advantages compared with other market instruments. In theory, if the goal is to maximize welfare, then taxation is superior to emissions trading [26,27], but Newell and Pizer pointed out that the cost of reducing carbon emissions offsets the gains from carbon taxes, which leads to a loss [28]. Karp and Zhang also pointed out that the carbon emissions trading system can cope better with these problems [29]. Murray et al. further pointed out that if the storage, banking, or borrowing of emission rights is allowed, the welfare effect of the cap-and-trade system will be better than the carbon tax [30]. Dong et al. indicated that the ETS significantly contributed greatly to reducing emissions [31]. Gao et al. pointed out that the ETS is a unique market mechanism to curb excessive GHG emissions, and its effectiveness has been a broad concern for governments and scholars [18]. Dong et al. indicated the carbon emissions trading policy significantly affects the co-benefits of the total carbon emissions reduction and air quality improvement [32].Zhang et al. stated that carbon emissions trading inhibits green technology innovation in the current stage but dramatically reduces carbon emissions [33] (as shown in Figure 8).

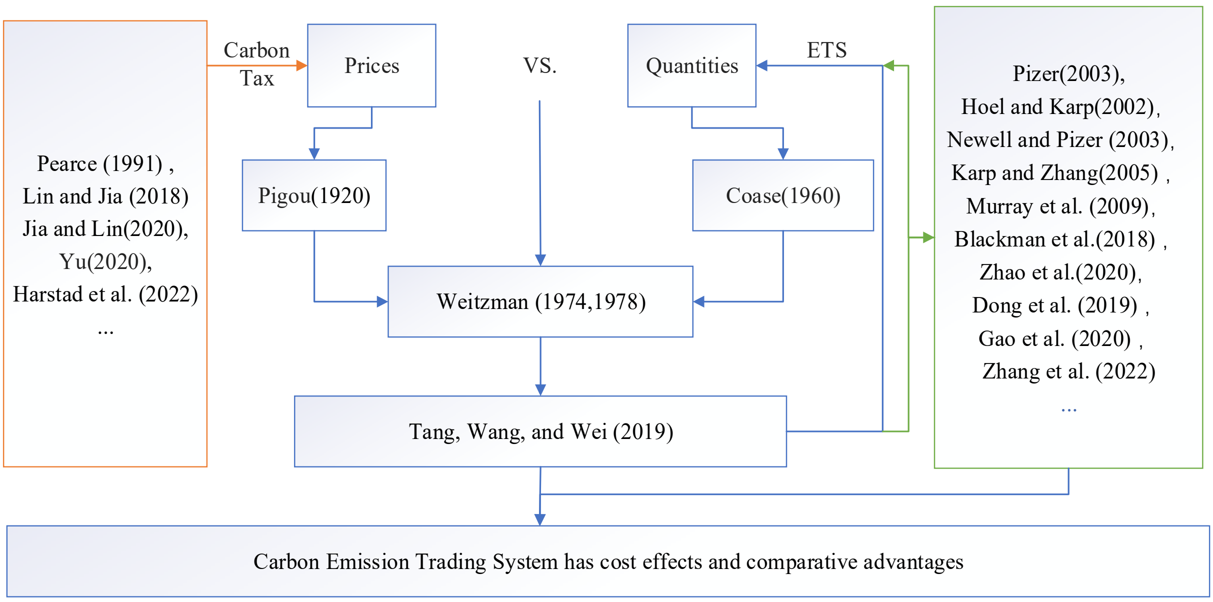

Figure 8. Prices vs. quantities; ETS has cost effects and comparative advantages [13–33].

As a result, the carbon emissions trading system has cost effects and comparative advantages in the short term based on previous research. Additionally, the research value of the carbon emissions trading system is increasing. Therefore, the ETS should be launched and improved gradually to reduce emissions and mitigate climate change, which cannot be separated from academic contributions.

4.2. Methods of Allowance Allocation in the ETS

The issue of allowance allocation as the critical component in ETS construction has also caused heated discussion among scholars. From the perspective of fairness [34–36] or efficiency [37,38], top-down or bottom-up [39–41], scholars try to create reasonable and accepted allowance allocation schemes. With a desire to assign the future allowable carbon emissions, researchers and supranational institutions reasonably and efficiently have put forward over 20 allocation proposals. Yet, none have been widely accepted by climate conferences [42]. Therefore, it is necessary to explore a better allowance allocation scheme.

There are two ways to allocate quotas: for free or by public auction (as shown in Figure 9). Coaseproposed that whether or not the transaction cost is zero, as long as the emissions rights are clearly defined, the market will realize resource allocation effectively and internalize the external cost [3]. Free allocation, with zero transaction costs, is generally considered to apply to the initial stage of the carbon emissions trading system due to its low execution resistance and easy implementation. Stavins believed that with the support of political power and energy sectors, it is predicted that EU countries will still maintain a free allocation plan based on grandfathering in the short term [43]. However, Woerdman feared that there may be a lack of enough financial capacity to support the operation of grandfathering [44]. Matthes and Neuhoff pointed out that the long-term continuous use of the free allocation method will pull down the efficiency of the emissions trading system [45]. Christian et al. recommended that emission allowance should be applied to benchmarking based on historical output data, but the proportion of free allocation should also gradually decrease [46].

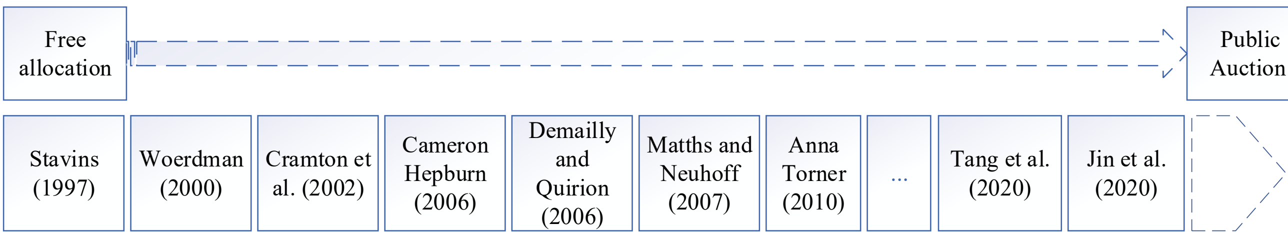

Figure 9. Scholars of study free allocation and public auction [43–56].

Although many enterprises favor free allocation due to the unpaid use of the environment and the unfairness toward newcomers, some scholars have proposed using pricing and auction methods to conduct carbon emissions trading more effectively. The most important and challenging problem in carbon pricing is determining the initial price. Many scholars proposed different techniques and ideas, such as the multi-variate analysis of environmental values [47], governance costs and the pollution pricing model [48], the shadow price pricing model [49–51], and so on. At present, more scholars believe that the auction method, a paid initial allocation method, is a better way to reflect the principles of fairness and justice and is suitable for carbon emissions trading. Demailly and Quirion pointed out that free allocation would make the dividends generated by the system tilt towards the regulated enterprises, and the overall improvement of society would be slight. This auction rule would be more effective [52]. In addition, Cramton et al. and Cameron Hepburn further pointed out that the auction method helps improve the efficiency of the carbon emissions trading system and maximizes government revenue [53,54]. The transition from free allocation to auction does not affect the products of regulated companies. Tang et al. simulated the marginal abatement cost curves of different sectors in China's ETS and calculated the optimal carbon price of sector coverage scenarios based on the criteria involving eight industries [55]. Jin et al. simulated a national ETS of ten carbon-intensive sectors with the mass-based, output-based allocation (OBA) of emission allowances [56].

The issue of allowance allocation is a critical part of the ETS. It is necessary to explore a better allowance allocation scheme. However, there are still some problems to be solved in allowance allocation schemes, such as cap setting, covering sectors, and the allocation method. It has been determined that bottom-up quota allocation schemes can achieve national emission reduction targets from the up-bottom. Additionally, due to the accuracy of carbon emission data from key emitting enterprises, how to ensure that caps are neither loose nor tight should be determined. The timing and order should be explored and determined for sectors stepping into the ETS to avoid a loss of national welfare or the failure of emissions reduction. Research on the initial allocation of carbon emission allowance mainly focuses on the methods, and the pilot cities launching the ETS mostly rely on free allocation. Free allocation is based on historical emissions, but this method could only be applied to the transitional stage. With ETS's development, the use of the principles of benchmarking and auctioning will be inevitable.

4.3. Research on the Impact of Allowance Allocation and Evidence from the Power Sector

Scholars have conducted qualitative and quantitative analyses from macro and micro perspectives to study the impact of different allowance allocation schemes. However, international scholars always focus on the EU ETS, RGGI, and other ETSs, exploring the cost, supply, and demand planning models and the micro depth analysis of the different allowance allocation schemes. They found that an increase in carbon costs led to varying fluctuations in the market price, which affects demand and changes in the returns of different types of firms.

From a macro perspective and based on the equilibrium model, Chinese scholars worked out different economic and environmental impacts of different allowance allocation plans. They mainly focused on the qualitative comparison between the allocation methods. Xu examined various allocation methods of the total allowable pollutant discharge in China according to the principles of fairness and benefit and pointed out the advantages and disadvantages of each technique [57]. Ding and Feng explored the policy considerations of different allocation methods, analyzed the fundamental factors at the Chinese and international levels, and then put forward suggestions regarding the allocation methods that should be established in China [58]. Qi and Wangconducted a comparative analysis of the mode and methods of initial allocation and obtained China's progressive mixed way of free allocation [59]. Li and Wang conducted a comparative study of the allocation methods in the six pilot provinces and cities which launched ETSs and found that the allocation methods of the pilot ETSs have specific common characteristics, but each one also has its own features [60]. At present, there is no unified allocation method.

Some scholars have researched the power industry and the impact of allowance allocation in the power industry. As a significant emission sector, most scholars have taken the power industry as an example because of the standardization of its emissions accounting and the fact that it is the first to be covered by the ETS. Based on different allocation schemes, they studied the macroeconomic, environmental, and micro enterprises costs and other effects.

Macroscopically, as shown in Table 5, Bohringer and Lange used the general equilibrium model to quantitatively analyze the economic impact of different allocation methods based on ten integrated sectors [61]. Li and Jia set ten free allowance ratio scenarios, using a dynamic equilibrium model to simulate the ETS. They explored the free ratio and carbon price relationship, measuring the economic and environmental impact [62]. Using eight different allocation schemes, Li et al. used the dynamic equilibrium model to measure its economic impact [63]. Based on the general equilibrium model, Zhanganalyzed the effect of different allocation schemes on the power industry and tried to propose a better allocation scheme for the power industry [64]. Lin and Jia set up six allocation scenarios, and the equilibrium model was used to analyze the energy, economic, and environmental impacts [17].

Table 5. Macroscopical research on the impact of allowance allocation in the power industry [17,60–64].

Title	Authors, Year	Regions	Model
Economic Implications of Alternative Allocation Schemes for Emission Allowances	Bohringer C, Lange A. 2005	EU and USA	CGE
The impact of emission trading scheme and the ratio of free quota: A dynamic recursive CGE model in China	Li W, Jia ZJ. 2016	China	CGE
The impact on electric power industry under the implementation of national carbon trading market in China: A dynamic CGE analysis	Wei Li, Yan-Wu Zhang, Can Lu. 2018	China	A dynamic CGE
Impact of carbon allowance allocation on power industry in China's carbon trading market: Computable General Equilibrium based analysis	Lirong Zhang, Yakun Li, Zhijie Jia. 2018	China	CGE
Impact of quota decline scheme of emission trading in China: A dynamic recursive CGE model	Boqiang Lin, Zhijie Jia. 2018	China	A dynamic recursive CGE model

At the micro level, scholars have adopted linear programming, equilibrium models, market simulation/multi-agents, etc., to explore the cost–benefit issues of power firms (as shown in Table 6). Burtraw et al. used the Haiku model to explore the power industry's cost and allocation effects of grandfathering, benchmarks, and auction allocation methods [65]. Neuhoff et al. used a comprehensive planning model (linear programming) to quantitatively analyze the ratio of firms' costs transferred to electricity prices and the final realized income under different allocation schemes [66–68]. Sijm, Chen and Lise used the enterprise competition and market power model (equilibrium model) in power transmission and energy simulation [69–72]. Additionally, they explored the transmission ratio of firms' costs to determine electricity prices under different allocation schemes.

Sterner and Muller used a simple multi-cycle model to study the impact of various free allocation schemes on incentives, emissions reductions, and outputs [73]. Zhou et al. modeled the Australian national electricity market in the ETS, based on historical emissions and historical power generation allocation methods, to analyze the potential profit impact and the possible compensation impact on the affected power generation companies [74]. Cong et al. used multi-agent modeling to measure the effect of different proportions of allowance auction schemes on electricity prices and power generation structures [75,76]. Westner and Madlener first showed that implementing the modified allocation mechanism significantly reduced the net present value of the power generation technology, then analyzed the decision-making problem [77]. Pierre and Boris explored the impact of fluctuations in carbon abatement costs on electricity prices using different theoretical and empirical models [78]. Ahn used a hybrid complementarity model to examine the effects of various initial allocation schemes on the Korean electricity market [79]. Liu et al. calculated the estimates of optimal power generation structures and technical structures at different auction rates and the cost of a reduction in China's power generation industry [80]. Goulde et al. assessed China's TPS's cost-effectiveness and distributional impacts on reducing CO_2 emissions from the power sector [81].

Table 6. Microscopical research on the impact of allowance allocation in the power industry [64–72].

Title	Authors, Year	Regions	Model
The Effect of Allowance Allocation on the Cost of Carbon Emission Trading	Dallas Burtraw, Karen Palmer, RanjitBharvirkar, and Anthony Paul. 2001	USA	Haiku model with an Industrial Sector Model (INSECT)
Allocation of carbon emission certificates in the power sector: how generators profit from grandfathered rights	Martinez KK; Neuhoff K. 2005	EU	Integrated Planning Model® (IPM)
Impact of the allowance allocation on prices and efficiency	Karsten Neuhoff, Michael Grubb and Kim Keats. 2005	EU	Analytic models and IPM
CO_2 cost pass-through and windfall profits in the power sector	Sijm J; Neuhoff K; Chen Y. 2006	Germany and Netherlands	COMPETES and IPM
Allocation, incentives and distortions: the impact of EU ETS emissions allowance allocations to the electricity sector	Neuhoff K; Martinez KK; Sato M. 2006	EU	IPM
Implications of CO_2 emissions trading for short-run electricity market outcomes in northwest Europe	Chen YH; Sijm J; Hobbs BF; Lise W. 2008	Nortwesern Europe	COMPETES
The Impact of the EU ETS on Prices, Profits and Emissions in the Power Sector: Simulation Results with the COMPETES EU20 Model	Lise W; Sijm J; Hobbs BF. 2010	EU	Carbon cost pass-through, COMPETES
CO_2 price dynamics: The implications of EU emissions trading for the price of electricity	J.P.M. Sijm, S.J.A. Bakker, Y. Chen H.W. Harmsen, W. Lise. 2005.	Nortwesern Europe	COMPETES model
Output and abatement effects of allocation readjustment in permit trade	Sterner T; Muller A. 2008	EU	A multiple-period model
Partial Carbon Permits Allocation of Potential Emission Trading Scheme in Australian Electricity Market	Zhou X; James G; Liebman A; Dong ZY; Ziser C. 2010	Australian	Australian National Electricity Market modeling
The impact of modified EU ETS allocation principles on the economics of CHP-based district heating systems	Westner G; Madlener R. 2012	EU	A spread-based real options model and discounted cash-flow model
An overview of CO_2 cost pass-through to electricity prices in Europe	Pierre-AndréJouvet, BorisSolier. 2013	EU	The marginal abatement cost function
Assessment of initial emission allowance allocation methods in the Korean electricity market	Jaekyun Ahn. 2014	Korea	A mixed complementarity problem (MCP) model
How will auctioning impact on the carbon emission abatement cost of electric power generation sector in China?	Liu LW; Sun XR; Chen CX; Zhao ED. 2016	China	The modified Trans-log production function, dynamic simulation model and multi-objective linear programming
China's unconventional nationwide CO_2 emissions trading system: Cost-effectiveness and distributional impacts	Lawrence H. Goulder, Xianling Long, Jieyi Lu, Richard D. Morgenstern. 2022	China	Analytically and numerically solved models

Based on the above research, most scholars use linear programming, equilibrium modeling, and multi-agent modeling to explore firms' cost and socio-economic and environmental impacts under different allocation schemes, which has excellent academic research value. However, due to the accuracy and availability of firms' emission data, the effectiveness and scientificalness of the quota allocation scheme for the power industry need to be demonstrated, leading to firms getting too many or too few quotas, thus affecting emission reduction and development of critical emitters.

Therefore, it has practical significance and realistic value to research the ETS, which has cost effects and comparative advantages in reducing emissions and mitigating climate change. The issue of allowance allocation as the critical component in the ETS has also caused heated discussion among scholars. In allowance allocation, exploring a desire to assign the future allowable carbon emissions reasonably and efficiently is critical, yet scholars widely do not accept this. Moreover, free allocation is applied to the transitional stage, and auctioning will be inevitable. In addition, scholars from macro and micro perspectives used linear programming, equilibrium modeling, and multi-agent modeling to explore the impact of different allowance allocation schemes and took the power industry as an example.

5. Conclusions and Discussion

Unlike previous research, this study presented a comprehensive and systematic literature review on the ETS, including its origin, core mechanism, research hotspots, and future research focus, using a bibliometric method and combining in-depth qualitative analysis. This study explored the practical problems and research gaps in constructing the ETS. In conclusion, it is necessary to research the ETS to mitigate climate change and reduce emissions at a low cost. As the carbon market is paid much attention, the issue of allowance allocation as the critical component in ETS construction has also caused heated discussion among scholars. In allowance allocation, exploring a desire to assign the future allowable carbon emissions reasonably and efficiently is critical, yet scholars widely do not accept this. Moreover, free allocation is based on historical emissions, but this method can only be applied to the transitional stage. With the development of the ETS, the use of the principles of benchmarking and auctioning will be inevitable. In addition, scholars have carried out qualitative and quantitative analyses from macro and micro perspectives to study the impact of different allowance allocation schemes and took the power industry, the largest emitter sector, as an example. Most scholars use linear programming, equilibrium modeling, and multi-agent modeling to explore firms' cost and socio-economic and environmental impacts under different allocation schemes. However, due to the accuracy of industry data, the quota allocation scheme needs to be improved.

Launching the ETS to mitigate climate change effectively and reduce emissions at a low cost is necessary. However, different emission reduction commitments of each country lead to different levels of progress in carbon market construction. Countries launching the ETS are gradually improving their core mechanisms, such as allowance allocation, cap setting, covering sectors, and the allocation method. However, due to the accuracy of obtaining historical quota data, the effect of the quota allocation scheme needs to be improved, including how to set neither loose nor tight caps and construct a quota allocation scheme with effective emission reduction and cost. Regarding sectors stepping into the ETS, it is vital to determine the ordering and timing. Moreover, in terms of the allocation method, auctioning will be inevitable in the future, but the dynamic timing of the shift from free to auction quotas is worth exploring. All these problems need to be further studied. Countries not launching the ETS lack the responsibility and confidence to actively mitigate climate change, which has caused widespread adverse impacts and related losses and damages to nature and people beyond natural climate variability (IPCC,2022). They should reduce emissions through energy restructuring, clean energy, and technology development and upgrading instead of the ETS, but they will face high emission reduction costs if they do. Carbon markets can be an excellent way to balance emissions and development.

6. Policy Implications

Governments are encouraged to launch the ETS to reduce emissions and combat climate change. This paper showed that the emissions trading system has cost effects and comparative advantages of reducing emissions and mitigating climate change. Additionally, it is also an object of excellent academic and research value, which is indicated by the amount and distribution of the publications, journal distribution, productive authors, and institutions. Therefore, it is critical to research the ETS and its research, including the initial allowance allocation, its impact, and the empirical analysis focusing on the largest emitter, the power sector. According to research on the ETS, governments can obtain scientific advice on how to launch the ETS and gradually improve its core mechanics. For countries establishing the ETS, governments should enhance their core mechanisms, such as allowance allocation. For countries not launching the ETS, carbon markets can be an excellent way to balance emissions and development in the future, which do not pay for energy restructuring, clean energy, and technology development and upgrading. In addition, external factors and development influence ETS launches, such as sudden international political events. This year, the tension between Russia and Ukraine triggered pessimism about the carbon market. It led to the large-scale selling of carbon quotas, seriously affecting the ETS's sustainable development. Moreover, some international negotiations could help boost the ETS, such as COP21, COP26, and so on. Therefore, in constructing the ETS, the government should treat and respond to the influence of external factors reasonably and effectively.

The ETS should be improved gradually, including the improvement of issues such as cap setting, covering sectors, and the allocation method. To better reduce emissions and mitigate climate change, the ETS should be progressively enhanced to play its role in reducing emissions at low costs. In the process of carbon trading in various countries, quota allocation has always been complex. Therefore, allocating allowance effectively and somewhat reasonably is crucial, which involves determining how to set a reasonable cap, when and who is stepping into the ETS, and how to select a scientific and rational allocation method. Regarding cap setting, top-down and bottom-up approaches should be well docked. Namely, bottom-up quota allocation schemes can achieve national emission reduction targets. Additionally, the carbon emission data of key emitting enterprises should be obtained accurately, ensuring that caps are neither loose nor tight. Regarding sectors stepping into the ETS, the timing and order should be explored and determined to avoid a loss of national welfare or the failure of emissions reduction. In terms of the allocation method, auctioning will be inevitable in the future, but the pace of the shift from free to auction quotas is worth exploring. Auctioning at the right time is more acceptable for participants in the ETS.

Some key emission sectors and regions can be taken as the research and practice objects in the initial stage of the ETS. The ETS will initially only cover the more significant emitters. This paper found that most scholars focus on research on allowance allocation in the power industry, trying to microscopically analyze the impact of different allocation schemes, such as free and auctioning schemes, the cost and cost transfer, firms' income, and electricity prices in the market. However, due to the accuracy and availability of firms' emission data, the effectiveness and scientificalness of the quota allocation scheme for key emitters such as the power industry need to be demonstrated, leading to firms getting too many or too few quotas, thus affecting emission reduction and the development of critical emitters. Regarding the regions, some regions with good growth and resource endowment can be used as pilot areas to accumulate experience for national ETS construction. However, the determination of how to solve the problem of docking between the pilot and ETS is also very important. In general, the research and practice of critical sectors and pilot regions aim to improve the country's effective emission reduction mechanism and fully play its role in addressing climate change.

Author Contributions: Conceptualization, methodology, writing—original draft preparation, funding acquisition, Y.-J.H.; investigation, methodology, L.Y.; data curation, software, F.D.; formal analysis, validation, resources, H.W. and C.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by [National Natural Science Foundation of China] grant number [72104062], [Humanities and Social Science Research Youth Fund project of the Ministry of Education] grant number [21YJC630041], and [Key Laboratory of "Internet+" Collaborative Intelligent Manufacturing in Guizhou Provence] grant number [20165103].

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. IPCC. *Climate Change 2022: Mitigation of Climate Change*; Skea, J., Shukla, P.R., Slade, R., al Khourdajie, A., van Diemen, R., McCollum, D., Pathak, M., Some, S., Vyas, P., Fradera, R., et al., Eds.; IPCC: Geneva, Switzerland, 2022.
2. ICAP. *Emissions Trading Worldwide: Status Report 2022*; ICAP: Berlin, Germany, 2022.
3. Coase, R.H. The Problem of Social Cost. *J. Law Econ.* **1960**, *3*, 1–44. [CrossRef]
4. Cañas-Guerrero, I.; Mazarrón, F.R.; Calleja-Perucho, C.; Pou-Merina, A. Bibliometric analysis in the international context of the "Construction & Building Technology" category from the Web of Science database. *Constr. Build. Mater.* **2014**, *53*, 13–25.
5. Du, H.; Li, B.; Brown, M.A.; Mao, G.; Rameezdeen, R.; Chen, H. Expanding and shifting trends in carbon market research: A quantitative bibliometric study. *J. Clean. Prod.* **2015**, *103*, 104–111. [CrossRef]
6. Kiriyama, E.; Kajikawa, Y.; Fujita, K.; Iwata, S. A lead for transvaluation of global nuclear energy research and funded projects in Japan. *Appl. Energy* **2013**, *109*, 145–153. [CrossRef]
7. Wei, Y.-M.; Mi, Z.-F.; Huang, Z. Climate policy modeling: An online SCI-E and SSCI based literature review. *Omega* **2015**, *57*, 70–84. [CrossRef]
8. Yu, H.; Wei, Y.-M.; Tang, B.-J.; Mi, Z.; Pan, S.-Y. Assessment on the research trend of low-carbon energy technology investment: A bibliometric analysis. *Appl. Energy* **2016**, *184*, 960–970. [CrossRef]
9. Zhang, K.; Wang, Q.; Liang, Q.-M.; Chen, H. A bibliometric analysis of research on carbon tax from 1989 to 2014. *Renew. Sustain. Energy Rev.* **2016**, *58*, 297–310. [CrossRef]
10. Wang, X.-Y.; Tang, B.-J. Review of comparative studies on market mechanisms for carbon emission reduction: A bibliometric analysis. *Nat. Hazards* **2018**, *94*, 1141–1162. [CrossRef]
11. Ji, C.J.; Li, X.Y.; Hu, Y.J.; Wang, X.Y.; Glade, T.; Murty, T.S. Research on carbon price in emissions trading scheme: A bibliometric analysis. *Nat. Hazards* **2019**, *99*, 1381–1396. [CrossRef]
12. Tang, L.; Wang, H.; Li, L.; Yang, K.; Mi, Z. Quantitative models in emission trading system research: A literature review. *Renew. Sustain. Energy Rev.* **2020**, *132*, 110052. [CrossRef]
13. Hepburn, C. Regulation by Prices, Quantities, or Both: A Review of Instrument Choice. *Oxf. Rev. Econ. Policy* **2006**, *22*, 226–247. [CrossRef]
14. Weitzman, M. *Prices vs. Quantities*; Massachusetts Institute of Technology (MIT), Department of Economics: Cambridge, MA, USA, 1973.
15. Weitzman, M.L. Optimal Rewards for Economic Regulation. *Am. Econ. Rev.* **2001**, *68*, 683–691.
16. Pierce, D. The role of carbon taxes in adjusting to global warming. *Econ. J.* **1991**, *101*, 938–948. [CrossRef]
17. Lin, B.; Jia, Z. Impact of quota decline scheme of emission trading in China: A dynamic recursive CGE model. *Energy* **2018**, *149*, 190–203. [CrossRef]
18. Gao, Y.; Li, M.; Xue, J.; Liu, Y. Evaluation of effectiveness of China's carbon emissions trading scheme in carbon mitigation. *Energy Econ.* **2020**, *90*, 104872. [CrossRef]
19. Jia, Z.; Lin, B. Rethinking the choice of carbon tax and carbon trading in China. *Technol. Forecast. Soc. Chang.* **2020**, *159*, 120187. [CrossRef]
20. Harstad, B.; Lancia, F.; Russo, A. Prices vs. quantities for self-enforcing agreements. *J. Environ. Econ. Manag.* **2022**, *111*, 102595. [CrossRef]
21. Tang, B.-J.; Wang, X.-Y.; Wei, Y.-M. Quantities versus prices for best social welfare in carbon reduction: A literature review. *Appl. Energy* **2019**, *233–234*, 554–564. [CrossRef]
22. Zhao, L.; Yang, C.; Su, B.; Zeng, S. Research on a single policy or policy mix in carbon emissions reduction. *J. Clean. Prod.* **2020**, *267*, 122030. [CrossRef]
23. Allen, B.; Li, Z.; Liu, A.A. Efficacy of Command-and-Control and Market-Based Environmental Regulation in Developing Countries. *Annu. Rev. Resour. Econ.* **2018**, *10*, 381–404. [CrossRef]
24. Wei, C. China's urban CO_2 marginal abatement costs and its influencing factors. *World Econ.* **2014**, *431*, 115–137.
25. Soto, H.D. *The Mystery of Capital: Why Capitalism Triumphs in the West and Fails Everywhere Else*; Basic Books: New York, NY, USA, 2000.
26. Hoel, M.; Karp, L. Taxes versus quotas for a stock pollutant. *Resour. Energy Econ.* **2002**, *24*, 367–384. [CrossRef]
27. Hoel, M.; Karp, L. Taxes vs. Quotas for a Stock Pollutant with Multiplicative Uncertainty. *Resour. Energy Econ.* **2001**, *82*, 91–114.

28. Newell, R.G.; Pizer, W.A. Regulating stock externalities under uncertainty. *J. Environ. Econ. Manag.* **2003**, *45*, 416–432. [CrossRef]
29. Larry Karp, J.Z. Regulation of Stock Externalities with Correlated Abatement Costs. *Environ. Resour. Econ.* **2005**, *32*, 273–300. [CrossRef]
30. Murray, B.C.; Newell, R.G.; Pizer, W.A. Balancing Cost and Emissions Certainty: An Allowance Reserve for Cap-and-Trade. *Rev. Environ. Econ. Policy* **2009**, *3*, 84–103. [CrossRef]
31. Dong, F.; Dai, Y.; Zhang, S.; Zhang, X.; Long, R. Can a carbon emission trading scheme generate the Porter effect? Evidence from pilot areas in China. *Sci. Total Environ.* **2019**, *653*, 565–577. [CrossRef]
32. Dong, Z.; Xia, C.; Fang, K.; Zhang, W. Effect of the carbon emissions trading policy on the co-benefits of carbon emissions reduction and air pollution control. *Energy Policy* **2022**, *165*, 112998. [CrossRef]
33. Zhang, W.; Li, G.; Guo, F. Does carbon emissions trading promote green technology innovation in China? *Appl. Energy* **2022**, *315*, 119012. [CrossRef]
34. Ringius, L.; Torvanger, A.; Holtsmark, B. Can multi-criteria rules fairly distribute climate burdens?: OECD results from three burden sharing rules. *Energy Policy* **1998**, *26*, 777–793. [CrossRef]
35. William, N. *A Question of Balance: Weighing the Options on Global Warming Policies*; Yale University Press: London, UK, 2008; Volume 9, pp. 146–147.
36. Rose, A.; Stevens, B.; Edmonds, J.; Wise, M. International Equity and Differentiation in Global Warming Policy. *Environ. Resour. Econ.* **1998**, *12*, 25–51. [CrossRef]
37. Miao, Z.; Geng, Y.; Sheng, J. Efficient allocation of CO_2 emissions in China: A zero sum gains data envelopment model. *J. Clean. Prod.* **2016**, *112*, 4144–4150. [CrossRef]
38. Wang, K.; Zhang, X.; Wei, Y.-M.; Yu, S. Regional allocation of CO_2 emissions allowance over provinces in China by 2020. *Energy Policy* **2013**, *54*, 214–229. [CrossRef]
39. Ellerman, A.D.; Buchner, B.K. The European Union Emissions Trading Scheme: Origins, Allocation, and Early Results. *Rev. Environ. Econ. Policy* **2007**, *1*, 66–87. [CrossRef]
40. Betz, R.; Eichhammer, W.; Schleich, J. Designing National Allocation Plans for Eu-Emissions Trading—A First Analysis of the Outcomes. *Energy Environ.* **2004**, *15*, 375–425. [CrossRef]
41. Betz, R.; Rogge, K.; Schleich, J. EU emissions trading: An early analysis of national allocation plans for 2008–2012. *Clim. Policy* **2006**, *6*, 361–394. [CrossRef]
42. Wei, Y.-M.; Zou, L.-L.; Wang, K.; Yi, W.-J.; Wang, L. Review of proposals for an Agreement on Future Climate Policy: Perspectives from the responsibilities for GHG reduction. *Energy Strategy Rev.* **2013**, *2*, 161–168. [CrossRef]
43. Stavins, R.N. Policy Instruments for Climate Change: How Can National Governments Address a Global Problem? *Univ. Chic. Leg. Forum* **1997**, *1997*, 10.
44. Woerdman, E. Implementing the Kyoto protocol: Why JI and CDM show more promise than international emissions trading. *Energy Policy* **2000**, *28*, 29–38. [CrossRef]
45. Matthes, F.C.; Neuhoff, K. *Auctioning in the European Union Emissions Trading Scheme*; Öko-Institut: Berlin, Germany; University of Cambridge: Cambridge, UK, 2007.
46. Egenhofer, C.; Georgiev, A.; Torner, A.; van den Bergh, H. *Benchmarking in the EU: Lessons from the EU Emissions Trading System for the Global Climate Change Agenda*; CEPS Task Force Report, 11 June 2010; Centre for European Policy Studies: Brussels, Belgium, 2022.
47. Li, S.; Wang, J. The impact of the transaction under the different distribution of initial emission rights on the market structure. *J. Wuhan Univ. Technol. (Transp. Sci. Eng. Ed.)* **2004**, *28*, 40–43.
48. Bangtao, H.T.W. Emissions trading pricing model based on governance cost and pollutant income. *Shanghai Manag. Sci.* **2004**, *6*, 34–36.
49. Min, H. Analysis of Shadow Price Model for Emission Permit Pricing. *Price Mon.* **2007**, *2*, 19–22.
50. Yunhua, L. On the pricing mechanism and influencing factors of the emissions trading market. *Contemp. Econ. Manag.* **2009**, *31*, 1–4.
51. Yan, L.; Wu, T. Initial allocation and transaction model of emission rights based on shadow price. *J. Chongqing Univ. Technol. (Soc. Sci. Ed.)* **2010**, *24*, 53–56.
52. Demailly, D.; Quirion, P. CO_2 abatement, competitiveness and leakage in the European cement industry under the EU ETS: Grandfathering versus output-based allocation. *Clim. Policy* **2006**, *6*, 93–113. [CrossRef]
53. Hepburn, C.; Grubb, M.; Neuhoff, K.; Matthes, F.; Tse, M. Auctioning of EU ETS phase II allowances: How and why? *Clim. Policy* **2006**, *6*, 137–160. [CrossRef]
54. Cramton, P.; Kerr, S. Tradeable carbon permit auctions: How and why to auction not grandfather. *Energy Policy* **2002**, *30*, 333–345. [CrossRef]
55. Tang, B.-J.; Ji, C.-J.; Hu, Y.-J.; Tan, J.-X.; Wang, X.-Y. Optimal carbon allowance price in China's carbon emission trading system: Perspective from the multi-sectoral marginal abatement cost. *J. Clean. Prod.* **2020**, *253*, 119945. [CrossRef]
56. Jin, Y.; Liu, X.; Chen, X.; Dai, H. Allowance allocation matters in China's carbon emissions trading system. *Energy Econ.* **2020**, *92*, 105012. [CrossRef]
57. Baifu, X. Allowable Total Distributing Method and Equity-Benefit Principle. *Pollut. Prev. Technol.* **1994**, *1*, 14–16.
58. Ding Ding, F.J. On the choice of China's carbon trading quota allocation method. *Int. Bus. (J. Univ. Int. Bus. Econ.)* **2013**, *1*, 83–92.

59. Qi, S.; Wang, B. Initial quota allocation for carbon trading: A comparative analysis of patterns and methods. *J. Wuhan Univ. (Philos. Soc. Sci. Ed.)* **2013**, *5*, 19–28.
60. Li, F.; Wang, W. Comparative Research on Quota Allocation Methods in China's Pilot Carbon Market. *Res. Econ. Manag.* **2015**, *36*, 9–15.
61. Böhringer, C.; Lange, A. Economic Implications of Alternative Allocation Schemes for Emission Allowances: A Theoretical and Applied Analysis. *ZEW Discuss. Pap.* **2003**, *107*, 563–581.
62. Li, W.; Jia, Z. The impact of emission trading scheme and the ratio of free quota: A dynamic recursive CGE model in China. *Appl. Energy* **2016**, *174*, 1–14. [CrossRef]
63. Li, W.; Zhang, Y.-W.; Lu, C. The impact on electric power industry under the implementation of national carbon trading market in China: A dynamic CGE analysis. *J. Clean. Prod.* **2018**, *200*, 511–523. [CrossRef]
64. Zhang, L.; Li, Y.; Jia, Z. Impact of carbon allowance allocation on power industry in China's carbon trading market: Computable general equilibrium based analysis. *Appl. Energy* **2018**, *229*, 814–827. [CrossRef]
65. Burtraw, D.; Palmer, K.; Bharvirkar, R.; Paul, A. The Effect on Asset Values of the Allocation of Carbon Dioxide Emission Allowances. *Electr. J.* **2002**, *15*, 51–62. [CrossRef]
66. Neuhoff, K.; Åhman, M.; Betz, R.; Cludius, J.; Ferrario, F.; Holmgren, K.; Pal, G.; Grubb, M.; Matthes, F.; Rogge, K.; et al. Implications of announced phase II national allocation plans for the EU ETS. *Clim. Policy* **2006**, *6*, 411–422. [CrossRef]
67. Neuhoff, K.; Grubb, M.; Keats, K. Impact of the allowance allocation on prices and efficiency. *Camb. Work. Pap. Econ.* **2005**, 19–603. [CrossRef]
68. Neuhoff, K.; Martinez, K.K.; Sato, M. Allocation, incentives and distortions: The impact of EU ETS emissions allowance allocations to the electricity sector. *Clim. Policy* **2006**, *6*, 73–91. [CrossRef]
69. Chen, Y.; Sijm, J.; Hobbs, B.F.; Lise, W. Implications of CO_2 emissions trading for short-run electricity market outcomes in northwest Europe. *J. Regul. Econ.* **2008**, *34*, 251–281. [CrossRef]
70. Lise, W.; Sijm, J.; Hobbs, B.F. The Impact of the EU ETS on Prices, Profits and Emissions in the Power Sector: Simulation Results with the COMPETES EU20 Model. *Environ. Resour. Econ.* **2010**, *47*, 23–44. [CrossRef]
71. Sijm, J.; Neuhoff, K.; Chen, Y. CO_2 cost pass-through and windfall profits in the power sector. *Clim. Policy* **2006**, *6*, 49–72. [CrossRef]
72. Sijm, J.P.M.; Bakker, S.J.A.; Chen, Y.; Harmsen, H.W.; Lise, W. CO_2 price dynamics: The implications of EU emissions trading for electricity prices & operations. In Proceedings of the 2006 IEEE Power Engineering Society General Meeting, Montreal, QC, Canada, 18–22 June 2006; p. 4.
73. Sterner, T.; Muller, A. Output and abatement effects of allocation readjustment in permit trade. *Clim. Chang.* **2008**, *86*, 33–49. [CrossRef]
74. Zhou, X.; James, G.; Liebman, A.; Dong, Z.Y.; Ziser, C. Partial Carbon Permits Allocation of Potential Emission Trading Scheme in Australian Electricity Market. *IEEE Trans. Power Syst.* **2010**, *25*, 543–553. [CrossRef]
75. Cong, R.-G.; Wei, Y.-M. Potential impact of (CET) carbon emissions trading on China's power sector: A perspective from different allowance allocation options. *Energy* **2010**, *35*, 3921–3931. [CrossRef]
76. Cong, R.-G.; Wei, Y.-M. Experimental comparison of impact of auction format on carbon allowance market. *Renew. Sustain. Energy Rev.* **2012**, *16*, 4148–4156. [CrossRef]
77. Westner, G.; Madlener, R. The impact of modified EU ETS allocation principles on the economics of CHP-based district heating systems. *J. Clean. Prod.* **2012**, *20*, 47–60. [CrossRef]
78. Jouvet, P.-A.; Solier, B. An overview of CO_2 cost pass-through to electricity prices in Europe. *Energy Policy* **2013**, *61*, 1370–1376. [CrossRef]
79. Ahn, J. Assessment of initial emission allowance allocation methods in the Korean electricity market. *Energy Econ.* **2014**, *43*, 244–255. [CrossRef]
80. Liu, L.; Sun, X.; Chen, C.; Zhao, E. How will auctioning impact on the carbon emission abatement cost of electric power generation sector in China? *Appl. Energy* **2016**, *168*, 594–609. [CrossRef]
81. Goulder, L.H.; Long, X.; Lu, J.; Morgenstern, R.D. China's unconventional nationwide CO_2 emissions trading system: Cost-effectiveness and distributional impacts. *J. Environ. Econ. Manag.* **2022**, *111*, 102561. [CrossRef]