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A bibliometric analysis of research on carbon tax from 1989 to 2014

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ABSTRACT

As one of the most cost-effective means of emission reduction, carbon tax has attracted considerable attention from economists and international organizations and has led to a large number of related research. Using the bibliometric method, this paper characterizes the carbon tax literature from 1989 to 2014 based on the Network Database Platform of Web of Science. The results indicate that the USA occupies a leading position in the carbon tax field. The Vrije University Amsterdam, Massachusetts Institute of Technology and Stanford University were the most productive research institutes. Energy Policy (143) has been the most productive journal followed by Energy Economics (44) and Energy (38). In general, the cooperation of authors, institutes and nations are continuing to strengthen; however, the growth rate at the author level was significantly higher than the others. In addition, the current key research areas in the carbon tax field based on Co-Keyword Analysis are as follows: climate change and relevant policy, carbon emissions trading, socio-economic effects of carbon tax, renewable energy, endogenous technological change and carbon capture and storage. The results of this paper will help researchers grasp the current research in the carbon tax field but also provide a supporting role for future work.

Contents

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1. Introduction

Public opinion and the political ecology environment of the reduction of global carbon dioxide emissions has been formed, although the scientific evidence of climate change is controversial and uncertain (particularly quantifying the relation between atmospheric greenhouse gas concentrations and temperature increment) [1]. Climate change may be enhanced if no measures are taken; furthermore, it may have serious, widespread and irreversible effects on humans and ecological systems [2]. For example, climate change is likely to cause adverse weather events in agriculture, such as drought, excessive moisture, hail, frost and flooding, which explain a high proportion of yield losses [3]. In the IPCC's recently released fifth assessment synthesis report, it once again stressed the following: currently, measures should be taken to encourage significant emission reductions over the next several decades to achieve the temperature target at the end of the 21st century, which limits the temperature rise to less than 2°C relative to pre-industrial levels [2]. Compared with the traditional measures (command and control policies) and technology mandates in reducing greenhouse gas emissions, market-based instruments have advantages in motivating the research and development in the technology of reducing emissions, thereby reducing the marginal cost [4,5]. Currently, there are generally two types of market-based instruments, one is the emission trading policy based on the amount of pollution control, namely, the carbon trading market [6,7]; the other is through the tax system or sewage charging policy based on price, namely, the carbon tax [5]. This paper will focus on the carbon tax.

Carbon tax is a tax levied on carbon dioxide for the purpose of mitigating global climate change. CO_2 emitted from the burning of fossil fuels (such as coal, oil and natural gas) is a major source of global carbon dioxide, and considering the practical operability, the carbon tax is usually taxed on the carbon content share of the fossil fuels. In other words, first, calculation of the carbon emissions from the fossil fuels is straightforward because a direct linear relation exists between the carbon content of fossil fuels and carbon emissions. Additionally, there are previously existing mature calculation methods (e.g., [8]) attributed to the long-term and outstanding work of the IPCC and other organizations. However, the method of establishing a reference system in the production process or deforestation to effectively measure carbon stock changes as well as devising an appropriate monitoring system has been a difficult technical problem [9]. Second, carbon dioxide emissions resulting from the fossil fuel combustion dominates total greenhouse gas (GHG) emissions. For example, of the 49 ($\pm$4.5) $GtCO_2eq/yr$ in total anthropogenic GHG emissions in 2010, fossil fuel-related CO_2 emissions attained 32 ($\pm$2.7) $GtCO_2/yr$, and grew further by approximately 3% between 2010 and 2011 and by approximately 1–2% between 2011 and 2012 [10]. Therefore, imposing a carbon tax on fossil fuel is prevalent among the current carbon tax practices; alternatively, the carbon tax structure is being designed because it can cover massive emissions at relatively low administrative costs.

A carbon tax is essentially a form of Pigovian tax. In 1920, the American economist Pigou (AC. Pigou) pointed out in his famous book of welfare economics: there is a gap between net marginal private cost and net marginal social cost because of the external environment, that is, an economic subject in its own activities did not get the corresponding reward or punishment when causing a beneficial or adverse impact on society and other people [11]. To eliminate this gap, national intervention is conducted to internalize externalities. That is, nations tax the unfavorable producers and move the economy into a healthy balance. This behavior is known as a Pigovian tax [11]. The carbon dioxide is a typical negative externality; economic subjects did not bear the corresponding cost for emitting CO_2 while in pursuit of maximizing economic benefits; therefore, differences between marginal private cost and social cost exist. However, carbon dioxide emissions can be effectively reduced, and social welfare can be increased through a carbon tax that internalizes the external costs of emitting CO_2 [12]. Although carbon tax, compare with carbon trading, has weaknesses such as lower political feasibility and greater uncertainty regarding the effect of emission reductions, much more economists are in favor of carbon tax due to its high and sustainable economic efficiency. For example, carbon taxes can provide continuous emission reduction incentives to potential emissions without limit, create sustained fiscal income, lower transaction costs; in addition, with carbon taxes the rent seeking and speculative possibility is small and there are greater incentives for increasing technological innovation. Furthermore, it will be easier to cooperatively entice the small emitter to the incentive system when compared with carbon emissions trading [13,14].

The international debate regarding the carbon tax originated in the 1990s when the world's largest economic and trade partner, the European Community (now the European Union), made a political commitment to reduce CO_2 emissions. After evaluating a series of measures to reduce emissions, the European Union finally selected carbon tax measures because these can produce long-term market signals and thus improve energy efficiency and reduce the use of fossil fuels [15]. In the 21st century, the European Union proactively introduced a carbon tax and has proposed an aviation or marine carbon tax; however, thus far the implementation of a carbon tax remains in stasis due to strong resistance by other countries. Conversely, the implementation process of carbon taxes in France can be described as twists and turns. France was ready to be the first to introduce a carbon tax: however, this forward progress was eventually canceled by the French Constitutional Council's veto. Compared with the EU or France, the US carbon tariff policy was proffered with highly controversial as well as bleak prospects because many countries have been very clearly against carbon tariffs.

Academic research on the issue of a carbon tax can be traced to the early 1990s; in addition, the number of documents will rapidly increase with the deepening of research on carbon tax. However, there remains a lack of research on the use of the bibliometrics method to sort and on the characteristic of carbon tax documents. Furthermore, it is necessary to strengthen such research to systematically assess the publishing features of carbon tax documents and understand the current research in the carbon tax field. The purpose of this study is to quantitatively and qualitatively evaluate the research literature related to carbon tax from 1989 to 2014 based on bibliometrics analysis. The main objective of this research is to address the following issues: (1) to investigate the growth trend of carbon tax literature production and the quantity of references; (2) to explore the literature from the perspective of the country of publication, publisher, and journal type of carbon tax documents; (3) to examine the prolific authors and highly cited literature; and (4) to discuss the current key research field and the carbon tax hot spots.

The remainder of the paper is structured as follows. Section 2 describes the research methods. Major results and their discussion are presented in Section 3. Section 4 presents the study's conclusions.

2. Methodology

In addition to basic statistical analyses, the methods used in this paper include: collaboration degree analysis, social network analysis, co-keyword analysis, as well as two types of evaluation

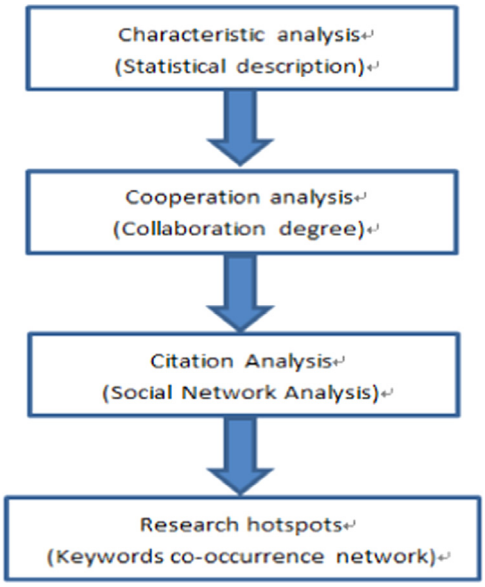

Fig. 1. Research content (methods).

indexes: the Impact Factor and the h-index. The framework of this research is shown in Fig. 1.

2.1. Collaboration degree analysis

The collaboration degree is a measure of the scientific research's connective relation to the level of authors, institutions and countries [16]; it is divided into three levels: the collaboration degree of the authors, institutions and countries. The calculation formula is as follows [17]:

Author's collaboration degree:

$$C_{Ai} = \frac{\sum_{j=1}^{N} \alpha_j}{N}$$

Institution's collaboration degree:

$$C_{Ii} = \frac{\sum_{j=1}^{N} \beta_j}{N}$$

Country's collaboration degree:

$$C_{Ci} = \frac{\sum_{j=1}^{N} \gamma_j}{N}$$

where: α_j, β_j, and γ_j are the number of authors, institutions and countries for each article; N is the annual total number of articles in the carbon tax field; and C_{Ai}, C_{Ii}, and C_{Ci} are the author, institution and country's collaboration degree of the i year.

2.2. Social network analysis

As shown in Fig. 1, this paper uses the social network analysis method to study the cooperation between authors, as well as the citation analysis. Social networks are a collection of social actors and their inter-relationships. The so-called “points” in the social network analysis are the various social actors; “edge” is a variety of social relationships between actors [18]. Social network analysis is a specific tool of social network theory, which is used to quantify the relationships between actors in the social network [19]. A formal description of social networks can be divided into a social network graph and a matrix of social relations. In the network graph, nodes represent social actors, and the connecting lead between the nodes represent the relationships between social actors. In the matrix, the rows and columns represent social actors, and the matrix element values indicate the relationship between social actors [19]. In this paper, we focus on a more intuitive social relationship network graph.

2.3. Keywords co-occurrence analysis

Keywords are an important part of the document that reflects the core content; through co-occurrence analysis of keywords, we can understand the developments and trends of a discipline [20]. In this paper, we employ keywords co-occurrence analysis to discuss the highly popular issues in the carbon tax field. Keywords co-occurrence analysis is derived from the idea of bibliometrics citation coupling and the co-cited notion, namely when two keywords that can express the research topic or direction in a particular subject appear in the same paper, this suggests that there is a certain internal relation between these two words, and the greater the number of occurrences, the closer the relation and the distance [21]. Co-word analysis is the utilization of vocabulary or a noun phrase occurring simultaneously in a literature collection to determine the relation between the various research themes among disciplines represented by the literature collection [22]. In this paper, we select keyword co-occurrence as a carrier of co-word analysis, using high frequency keyword co-occurrence cluster analysis methods to explore current research in the carbon tax field based on bibexcel software and Pajek visualization software.

2.4. The Impact factor and h-index

This paper uses the journal impact factor (IF)[1] to measure the impact of the journal. As an important tool in bibliometrics, the impact factor has played a vital role in the evaluation of the academic quality of journals, providing a reference regarding journal selection and scientific research output evaluation [23]. In 1995, Dr. Garfield, the founder of the Science Citation Index (SCI), first proposed the concept of impact factor in the scientific journal; since then, impact factors have increasingly been used to describe the influence of journals and authors. The journal impact factor used in this paper is from the journal citation reports (JCR).

Furthermore, this paper uses the h-index to measure the influence of the author. The h-index was proposed by Hirsch, an American physicist, in 2005 for the evaluation of individual academic achievement. Hirsch proposed that: “A scientist has index h if h of his or her N_p papers have at least h citations each and the other $N_p - h$ papers have less than h citations each” [24]. The H-index can more accurately reflect the individual's academic achievement; a higher h-index shows that the paper's larger influential power.

3. Results and discussion

The data used in this paper was derived from the Web of Science core collection, including Science Citation Index Expanded (SCI-E), Social Sciences Citation Index (SSCI), Conference Proceedings Citation Index-Science (CPCI-S), Conference Proceedings Citation Index-Social Science and Humanities (CPCI-SSH), Current

[1] Another popular index to assess the quality of journals is Eigenfactor; however, there are two reasons why this index was not employed here. First, Eigenfactor assigns each journal to one category, making it more difficult to compare across disciplines. Second, ceteris paribus, the value of the Eigenfactor score depends on the size of the journal (i.e., the number of papers published annually), thus it is not conducive for us to assess the quality of the journal.

Chemical Reactions (CCR-E) and Index Chemicus (IC). Furthermore, in this study, the field tags TS (= Topic), which contains titles, abstracts and keywords, were used to create the query. The TS= ("carbon tax*" OR "carbon emission tax*" OR "CO2 tax*" OR "CO2 emission tax*" OR "carbon dioxide tax*" OR "carbon dioxide emission tax*") was retrieved on January 11, 2015, and the retrieval records contain the title, author, keywords, abstract, and citation information. There were 1224 documents that do not include duplicates collected from 1989 to 2014. It should be noted that the United Kingdom (UK) in this study refers to England, Scotland, Wales and Northern Ireland. "China" refers solely to Mainland China, and articles from Hong Kong, Macao and Taiwan are excluded.

3.1. General statistics

A total of 12 document types were obtained by retrieval in this study (Table 1). As shown in Table 1, the article was the most frequently used document type representing 70.9% of the total publication, which was much higher than other types. The remaining publications were Proceedings paper (239; 18.3%), Editorial material (49; 3.7%), and Editorial material (42; 3.2%). Conversely, the top five document types represented 98.23% cumulative, which can represent all the literature. For language analysis, 5 languages were used by these documents, namely English, German, French, Chinese and Japanese. English is the dominant language with 1209 records, followed by German (7; 0.57%), French (4; 0.32%), Chinese (3; 0.24%) and Japanese (1; 0.08%).

Table 1
Document types distribution of the carbon tax literature.

Document type	Count	%	Cumulative (%)
Article	924	70.97	70.97
Proceedings paper	239	18.36	89.32
Editorial material	49	3.76	93.09
Review	42	3.23	96.31
News item	25	1.92	98.23
Letter	10	0.77	99.00
Note	4	0.31	99.31
Book chapter	4	0.31	99.62
Correction	2	0.15	99.77
Reprint	1	0.08	99.85
Meeting abstract	1	0.08	99.92
Biographical item	1	0.08	100.00
Total	1302	100.00	

The total publication, citation and the average citation per year are demonstrated in Fig. 2. The results show that the study of carbon tax exhibits an overall upward trend from 1989 to 2014, according to the literature, in the form of an increasing number. This trend can be approximately divided into two stages: 1989–2004, the annual quantity of literature published fluctuated, but is basically in a stable stage of development; 2005–2014, the quantity of literature published is in a stage of rapid development, and publications in 2014 increase to 181. Conversely, the annual total citations of carbon tax literature also generally showed an upward trend: in particular, for nearly 10 years, from 1989–2005, carbon tax literature citations grow from 0 to 178, but grew nearly exponentially within the next 10 years, achieving 1866 times in 2014. However, this figure also shows that, although the total publications and citations of carbon tax documents shows a fast-rising trend, the average citation per year has maintained a steady increasing trend from 2008 onwards at basically 9–11 times/year.

3.2. The analysis of countries and regions

Available literature on the carbon tax for the country and regional level analysis that provided affiliations for at least one author was used. Excluding 28 documents that lacked any author address information, a total of 1196 documents originate from 68 countries and regions. Table 2 presents the top 20 countries and regions' statistical information with regard to the number of total publications.

Table 2 shows that the USA was the most productive country with 281 documents representing 23.5%, followed by China (134; 11.2%) and the UK (133; 11.1%). Furthermore, the USA has the highest h-index of 28, which shows that it not only held a leadership position in the quantity of publications, but had a greater academic influence in the carbon tax field. In contrast, China was second to the USA in the number of total publications but ranked 10th by the h-index (11). This showed that China had a relatively smaller influence although it occupies an important position in the field.

Fig. 3 shows the annual publication output of the top 7 most productive countries and regions from 1991–2014. As shown in Fig. 3, the publications of these 7 countries and regions exhibit an

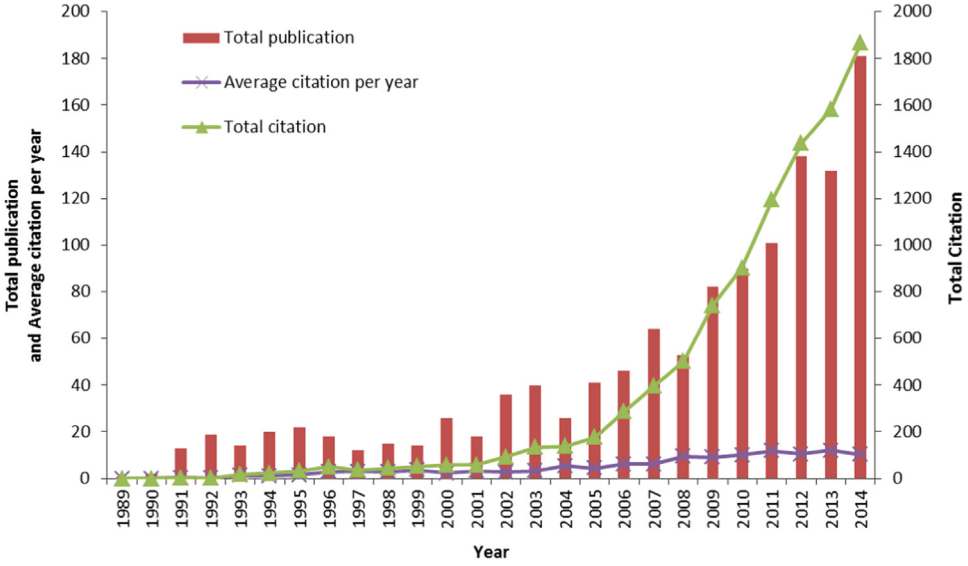

Fig. 2. The publication output performance of carbon tax documents.

upward trend. The USA had a leading position during nearly the entire period, and it focuses mainly on the carbon tax interaction with the electric power market, e.g., the emission reduction effectiveness of carbon taxes in the electricity industry as well as the effect of carbon tax on renewable electricity production. Other aspects of research includes whether carbon taxes can effectively promote renewable energy (e.g., biofuels) as an alternative to fossil fuels and the analysis of the rationality and necessity regarding carbon tariffs (border adjustment measures). Compared with the USA, China has increasingly focused on carbon tax research in recent years, and the annual publication output has followed closely. In particular, the documents published in 2012–2014 (94) are more than twice that in 1991–2011 (41). In 2010, the National Development and Reform Commission (NDRC) and the Ministry of Finance (MOF) issued their joint special report, proposing that a carbon tax should be levied in China by 2012; this finding most likely contributed to the rapid growth of China's recent tax documents [25]. The remaining 5 countries have minimal differences with respect to annual publications. Developed countries dominate the field of carbon tax because China is the sole developing country among the top 7 countries. Based on Fig. 2 and 3, we can observe that the most productive countries and regions promote the growth of carbon tax documents.

Table 2
Top 20 most productive countries and regions in research on carbon tax field.

No.	Country	TP	%	h-index(R)
1	USA	281	23.495	28(1)
2	China	134	11.204	11(10)
3	UK	133	11.120	20(2)
4	Australia	81	6.773	13(7)
5	Japan	78	6.522	15(5)
6	Sweden	64	5.351	17(3)
7	Canada	63	5.268	12(9)
8	Netherlands	58	4.849	17(3)
9	Norway	53	4.431	11(10)
10	Germany	53	4.431	14(6)
11	France	49	4.097	10(13)
12	Switzerland	45	3.763	13(7)
13	Italy	36	3.01	9(14)
14	Austria	26	2.174	9(14)
15	South Korea	24	2.007	4(20)
16	Ireland	21	1.756	11(11)
17	Spain	20	1.672	6(18)
18	Denmark	20	1.672	8(16)
19	Taiwan	18	1.505	6(18)
20	India	15	1.254	7(17)

TP=Total publications, R=Rank.
Note: % (Percentage) refers to the ratio of one country's publications to total number of publications, The h-index is based on the number of papers of one country that are collected from the 1124 papers in this study rather than the total number of papers the country has published.

3.3. The analysis of research institutes

A total of 1001 institutes were collected from 1196 documents in this study. Table 3 shows the top 20 institutes' statistical information according to the number of total publications. Among the top 20 institutes, nine originated from the USA, which again indicates the USA's dominant position in the carbon tax field. This is followed by the UK, China, and Norway all with 2 research institutes and one each in the Netherlands, Ireland, Australia and Japan. Compared with Table 2, Canada, Germany, France, Switzerland, South Korea,

Table 3
Top 20 most productive institutes in research on carbon tax field.

No.	Institutes (country)	TP	%	h-index
1	Vrije University Amsterdam (Netherlands)	25	2.09	12
2	Massachusetts Institute of Technology (USA)	19	1.589	9
3	Stanford University (USA)	18	1.505	9
4	University of Cambridge (UK)	17	1.421	7
5	Stat Norway (Norway)	16	1.338	7
6	University of Oxford (UK)	14	1.171	7
7	Tsinghua University (China)	14	1.171	4
8	Harvard University (USA)	14	1.171	8
9	Carnegie Mellon University (USA)	14	1.171	8
10	University of Oslo (Norway)	13	1.087	6
11	University California-Berkeley (USA)	12	1.003	5
12	National Bureau of Economic Research (USA)	12	1.003	7
13	World Bank (USA)	11	0.92	3
14	University of Gothenburg (Sweden)	11	0.92	5
15	Economic and Social Research Institute (Ireland)	11	0.92	5
16	Yale University (USA)	10	0.836	4
17	University of Sydney (Australia)	10	0.836	4
18	Resources for the Future (USA)	10	0.836	5
19	National Institute for Environmental Studies (Japan)	9	0.753	5
20	Chinese Academy of Sciences (China)	9	0.753	5

TP=total publications.
Note: % refers to the percentage of total publications.

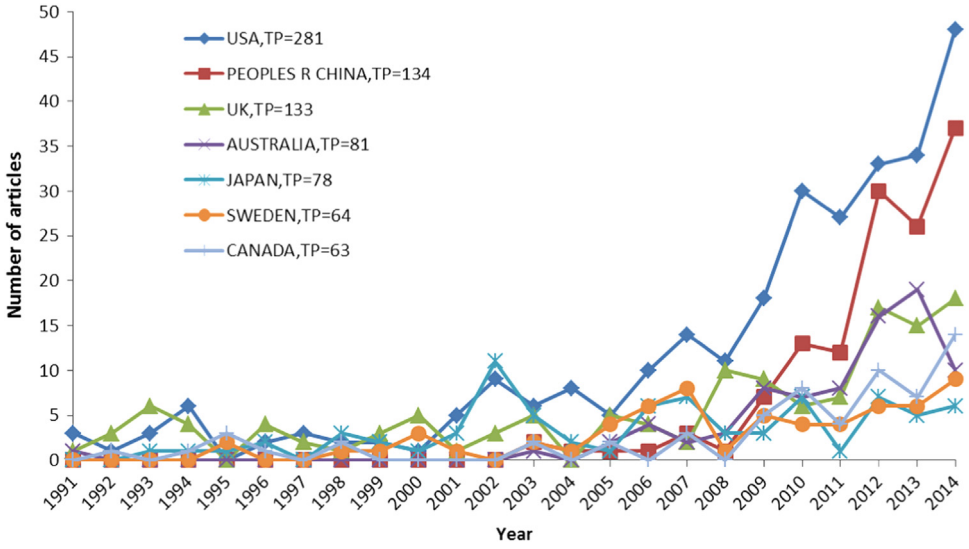

Fig. 3. Annual publication output of the top 7 most productive countries and regions (1991–2014).
Note: TP is the total number of the country's publications.

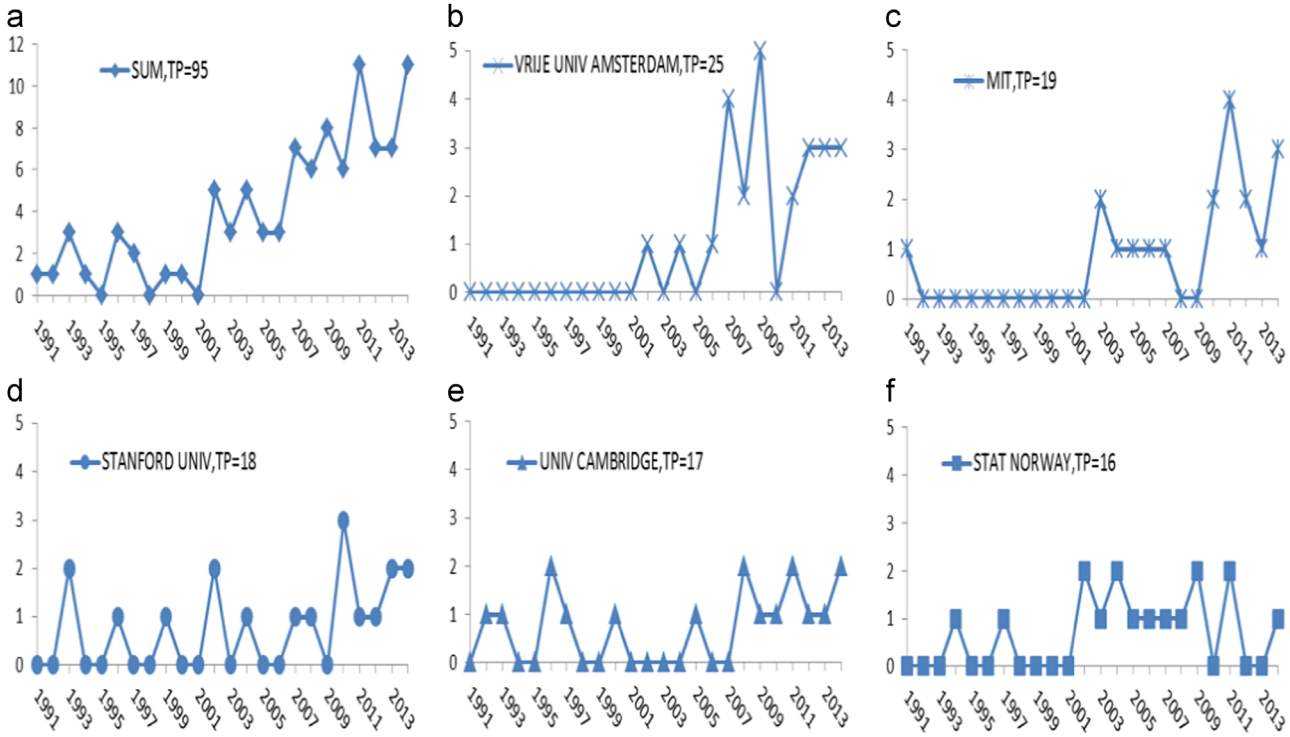

Fig. 4. Annual publication output of the top 5 most productive research institutes (1991–2014).
Note: TP: Total publications.

Spain, Denmark, Taiwan and India belonged to the 20 most productive countries; however, they had no institutes in the list of the top 20 most productive institutes. It was worth noting that the Vrije University Amsterdam ranked first whether in terms of the total publications (25) or the h-index (12). This finding indicated not only a higher focus on carbon tax research but also its great academic influence in this field. The Massachusetts Institute of Technology (19) was second to the Vrije University Amsterdam in the total number of publications, followed by Stanford University (18) and University of Cambridge (17). The Tsinghua University (14) and Chinese Academy of Sciences (9) in China were ranked 7th and 20th, respectively, by their publications.

Fig. 4 describes the time-trend analysis of the top 5 most productive research institutes. The sub-graph (a) in Fig. 4 presents the general evolution trend of the top 5 high-yielding institutions regarding the quantity of documents published, and the remaining five sub-graphs show the evolution trend of the top five institutions, respectively. Fig. 4 shows that there two institutes in the USA and one each in the Netherlands, the UK and Norway. The study of carbon taxes can be divided into two stages: prior to the 21st century, Stanford University, Cambridge University and Statistics Norway studied carbon tax; however, the general study trend is volatile. In the 21st century, nearly all the research institutions showed an increasing, fluctuating trend, particularly the Vrije University Amsterdam, which has had the most rapid increase, outperforming other research institutions. One reason is that the Vrije University Amsterdam has a number of famous scholars (e.g., Richard S.J. To and Frederick van der Ploeg) who study the carbon tax as systemic and profound.

3.4. The distribution of journals

The 1224 documents for carbon tax analysis were divided into 489 journals and 99 subject categories in this study. Table 4 shows the distribution of the top 20 productive journals, representing approximately 43.2% of the documents. Energy Policy was the most productive journal with 142 documents representing 11.6%; in addition, it ranked first in the subject category of Energy Fuels. The second productive journal was Energy Economics (44; 3.6%), which ranked first in the subject category of Economics. Energy was the third most productive journal (38; 3.1%) and ranked first in the subject category of Thermodynamic. Furthermore, the journal, Renewable and Sustainable Energy Reviews, was ranked 12th with respect to total publications; however, its impact factor of as much as 5.51 ranked first. Another journal that had an impact factor above 5 was Environmental Science and Technology (5.48). In addition, Table 4 shows that carbon tax research can be considered an interdisciplinary field, and Energy Fuels (443), Environmental Studies (370) and Environmental Sciences (344) were the top 3 subject categories with the most publications on research in the carbon tax field.

For comparison, the growth trend of the top 5 productive journals is presented in Fig. 5. As shown in Fig. 5, Energy Policy was the most productive journal; it nearly had a leading position during the entire period in the total number of publications from 1991 to 2014. Although there was volatility in the short term, the growth showed an upward trend in general. Conversely, the remainder of the four types of high-yielding journals shown increased but with a lower growth rate, and the number of annual publications regarding carbon tax will have difficulty exceeding the Energy Policy journal in the short term.

3.5. Cooperation analysis

3.5.1. General trends of cooperation among authors, institutes, and countries

There were 1196 remaining for cooperation analysis in the literature after excluding 28 anonymous carbon tax studies because they lacked any author address information. Fig. 6 shows the collaboration degree at the country, institution and author levels in the carbon tax field. In general, the three levels of collaboration degree rise over time, which shows that the relations between

Table 4
Top 20 most productive journals in research on carbon tax field.

Journal	R	TP	IF	%	Subject Category (TP/TP of SC)
Energy Policy	1	142	2.696(9)	11.601	Energy fuels (142/443) Environmental sciences (142/344) Environmental studies (142/370)
Energy Economics	2	44	2.58(10)	3.595	Economics (44/293)
Energy	3	38	4.159(5)	3.105	Energy fuels (38/443) Thermodynamics (38/64)
Applied Energy	4	34	5.261(3)	2.778	Energy fuels (34/443) Engineering chemical (34/95)
Ecological Economics	5	31	2.517(12)	2.533	Ecology (31/41) Economics (31/293) Environmental sciences (31/344) Environmental studies (31/370)
Journal of Environmental Economics and Management	6	25	2.522(11)	2.042	Business (25/33) Economics (25/293) Environmental studies (25/370)
Climate Policy	7	22	1.703(14)	1.797	Environmental studies (22/370) Public administration (22/33)
Energy Journal	8	21	1.864(13)	1.716	Economics (21/293) Energy fuels (21/443) Environmental studies (21/370)
Environmental and Resource Economics	9	21	1.703(14)	1.716	Economics (21/293) Environmental studies (21/370)
Advanced Materials Research	10	18	NA	1.471	NA
Energy Conversion and Management	11	18	3.59(6)	1.471	Energy fuels (18/443) Mechanics (18/19) Physics nuclear (18/19) Thermodynamics (18/64)
Renewable and Sustainable Energy Reviews	12	16	5.51(1)	1.307	Energy fuels (16/443)
Resource and Energy Economics	13	15	1.404(16)	1.225	Economics (15/293) Energy fuels (15/443) Environmental sciences (15/344) Environmental studies (15/370)
Climatic Change	14	14	4.622(4)	1.144	Environmental sciences (14/344) Meteorology atmospheric sciences (14/29)
Oil Gas Journal	15	14	NA	1.144	Energy fuels (14/443) Engineering petroleum (14/17)
Energy Procedia	16	13	NA	1.062	NA
Environmental Science & Technology	17	12	5.481(2)	0.980	Engineering environmental (12/77) Environmental sciences (12/344)
New Scientist	18	12	0.379(17)	0.980	Multidisciplinary Sciences (12/37)
Renewable Energy	19	10	3.361(7)	0.817	Energy fuels (10/443)
International Journal of Hydrogen Energy	20	9	2.93(8)	0.735	Chemistry physical (9/9) Electrochemistry (9/11) Energy fuels (9/443)

R=rank, TP=total publications, IF=impact factor (2013), SC=subject category, NA=not found.
Note: % refers to the percentage of total publication for a certain journal.

these were gradually strengthened. Compared with the cooperation between countries and institutions, the author's level shows the fastest growing collaboration degree, and each article has 3 authors on average since 2010; this finding suggests that the authors tended to collaborate more with those within the same institutions or within the same country. The results also clearly indicated that each article has 2 institutions on average after 2013, and the internationally collaboration was experiencing relatively slow growth.

3.5.2. *The performance of high-yielding authors*

Compared with the slow development of cooperation among institutions/countries, cooperation among authors showed a much higher extent and much faster growth. Therefore, this section intends to delve further into information regarding the cooperation among authors by targeting the high-yielding authors.

A total of 2407 (no repeat count) were collected from 1196 documents in this study. Of the authors who have published documents, 9.7% (17) have done so in 6 and above; in addition, in this study, we solely focus on the top 10 most productive authors. Table 5 shows the top 10 authors statistical information with respect to the number of total publications. It can be observed that Tol RSJ and Gerlagh R, the top two high-yielding authors, are both from the Netherlands; therefore, the Vrije University Amsterdam ranked first in most productive institutions. Among the most high-yielding authors, Tol RSJ ranked first with regard to total publications, whereas Gerlagh R ranked first regarding total citations and the h-index, which fully shows the importance and authority of this author in the carbon tax field. Furthermore, among the top 10 prolific authors, 8 authors are from developed countries, showing that developed countries dominate in the carbon tax field.

For further analysis of the collaboration relationship between high-yielding and other authors, the science mapping of author collaborations was developed for the most productive authors in carbon tax research using the Bibexcel and Pajek software. The collaboration network of the most productive authors (published more than 4 articles) is presented in Fig. 7. The nodes in the network represent the weights of the authors, and the size of lines between the nodes represents the cooperation relationships between authors. The figure shows that the most notable cooperation networks are Gerlagh, Rosendahl and Kverndokk as the

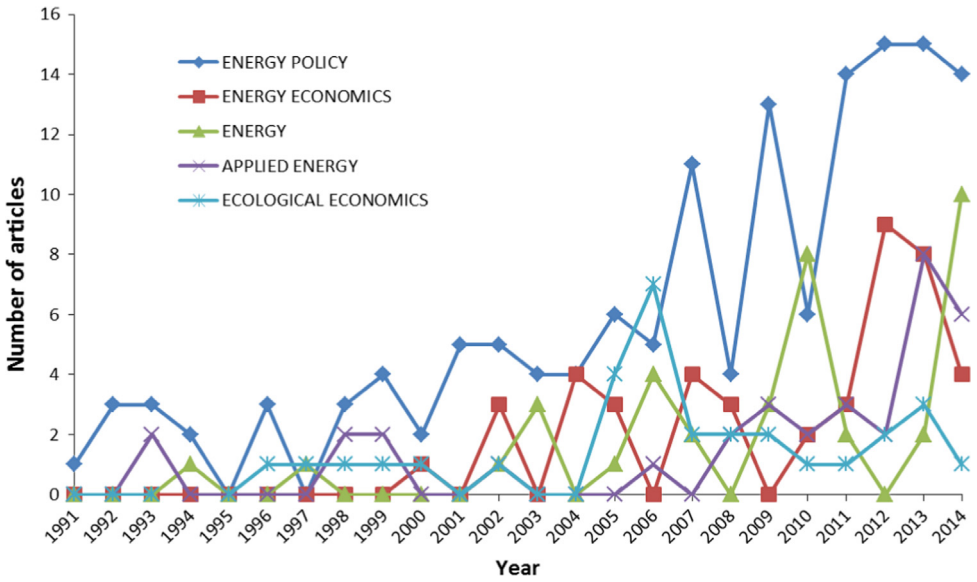

Fig. 5. The number of documents of the top 5 productive journals (1991–2014).

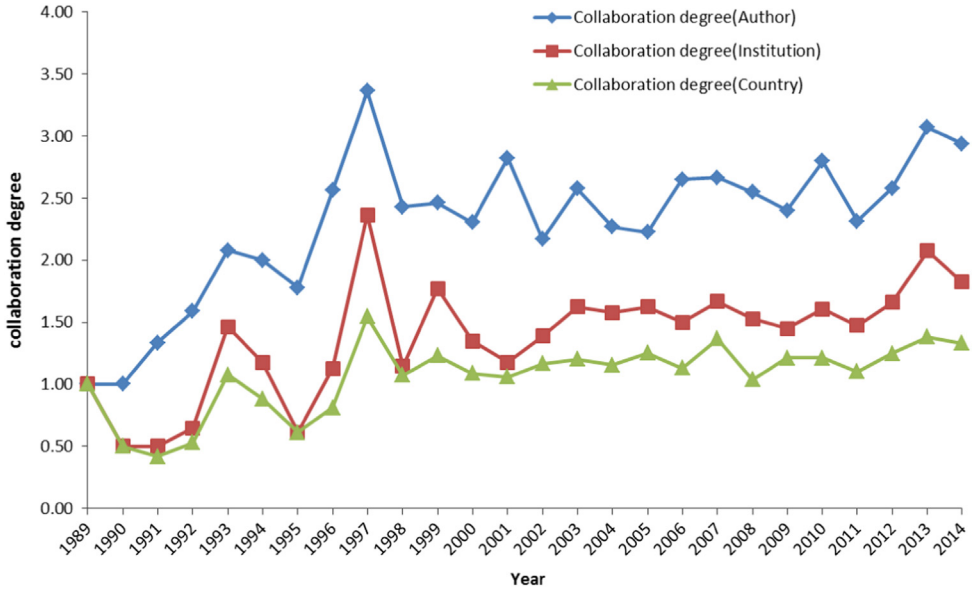

Fig. 6. Collaboration degree in the field of carbon tax (1989–2014).

center of the seven authors, as well as Qian as the center of the 4 authors' cooperation group. Moreover, the cooperation between prolific authors is mainly centered on two or three people. The analysis of the cooperation relationship between the most productive authors can help us more quickly become familiar with authoritative scholar cooperation network in the carbon tax field, which contributes to accurately understanding the research trends in this field.

3.6. Citation Analysis

The most authoritative carbon tax studies can help researchers quickly understand the carbon tax research area and its development trajectory. Whether a study is authoritative can be judged from two aspects, one is whether the study is the most cited by the literature regarding carbon tax, another is whether the study is the most cited among carbon tax documents. The former aspect refers to the studies that appeared most frequently in the references of carbon tax literature. This type of study may or may not be carbon tax literature. For example, the study could also regard the fundamental economics of carbon tax or the general theory of Pigovian tax. Determining such studies could provide information regarding what the carbon tax researchers are commonly reading when preparing their studies. The latter aspect refers to the most frequently cited carbon tax literature. This type of study could be cited by other carbon tax literature, or it could also be cited by literature that does not focus on carbon tax, e.g., a study that focused on mineral carbon sequestration [26]. Determining such studies could provide information regarding the characteristics of an excellent and popular carbon tax study, including the specific topics focused on and the layout style of the article. This section will analyze the authoritative carbon tax studies from the above two aspects.

First, the Bibexcel software is employed to extract the cited literature belonging to different authors; thus, the Pajek software was used to present a visual analysis of the cited literature. The

Table 5
Top 10 most productive authors in research on carbon tax field.

Number	Author	Country	TP(R)	%	TC	TC/year	h-index
1	Tol RSJ	Netherlands	12(1)	1.003	82(6)	6.83(7)	4
2	Gerlagh R	Netherlands	10(2)	0.836	228(1)	22.8(2)	6
3	Marechal F	Switzerland	8(3)	0.669	42(8)	5.25(8)	4
4	Rosendahl KE	Norway	7(4)	0.585	48(7)	6.86(6)	3
5	Nakata T	Japan	7(4)	0.585	105(5)	15(5)	5
6	Zhang ZX	China	6(5)	0.502	109(4)	18.17(4)	4
7	Shrestha RM	Thailand	6(5)	0.502	30(9)	5(9)	3
8	Schneider SH	USA	6(5)	0.502	166(2)	27.67(1)	4
9	Santarelli M	Italy	6(5)	0.502	26(10)	4.33(10)	3
10	Metcalf GE	USA	6(5)	0.502	119(3)	19.83(3)	5

TP=total production, R=Rank, TC=total citation.
Note: Country refers to the country where the author's first institution is located published article recently, The h-index is based on the number of papers of one author that are collected from the 1124 papers in this study rather than the total number of papers the author has published.

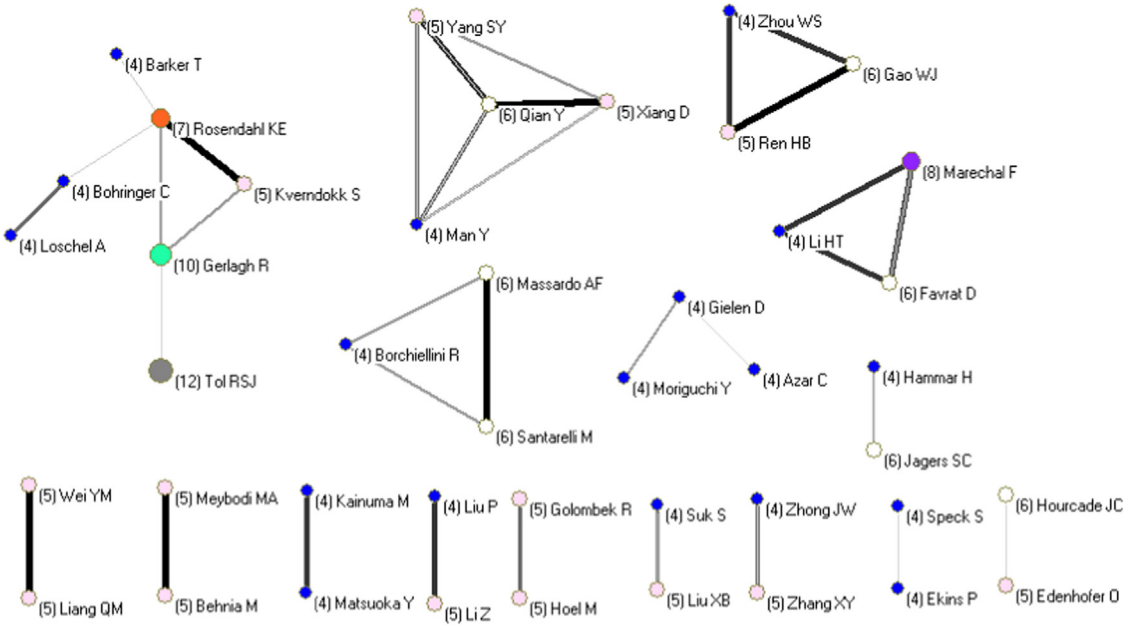

Fig. 7. The collaboration networks of the most productive authors.
Note: The cooperation relationship is represented by the lines between the two authors; and the thicker the line is, the stronger the collaboration is.

association network graph of the most frequently cited studies was shown in Fig. 8. As shown in Fig. 8, the earliest widely quoted literature related to carbon tax was “Welfare economics”, a classic masterpiece written by Pigou in 1920 [11]. This work proffered the theory of internalizing the external costs for the first time, that is, taxes on the polluters according to the degree of harm caused by pollution to compensate for such gap between the private and social costs associated with goods' production, which later became known as the “Pigovian tax”. The next authoritative research was written by Armington [27]. This researcher proposed the famous Armington hypothesis that allows for imperfect substitutability between domestic output sold domestically and imports. Furthermore, this hypothesis is widely used as an important theoretical support when developing the analytical framework of the carbon tax influence on an economic system. In the recent most cited literature, Nordhaus (2008) presents one of the most impressive analyses of greenhouse-gas emissions and climate change in an uncertain world and provides the tools to assess alternative approaches to mitigate global warming. Moreover, the author stresses that effective mechanisms (e.g., carbon taxes) should be established to harness markets and coordinate the efforts of different countries [28]. Metcalf deeply explored the design and effectiveness of the U.S. carbon tax from the perspective of the tax rate (involving the use of the revenues and rate changes over time), the issues of international trade, as well as the optimal tax base [29].

Next, we analyzed the most highly cited articles among the 1196 documents in the carbon tax field. Table 6 presented the top 10 most cited articles [30–39]. Of the ten studies, 5 were from the USA, 2 were from the UK, 1 each was from Italy, Canada and Germany. Moreover, a paper written by Leiserowitz (2006) [33] published in Climatic Change ranked first both in the total citations (258) and annual citations (25.8). This researcher examined the risk perception and policy preferences of the American public regarding carbon tax, and his results contributed to explaining the paradox of the American public's awareness of the risks of climate change. Namely, on the one hand, the American public actively supports national and international policies to mitigate climate change; on the other hand, they strongly opposed a carbon tax proposal. “An optimal transition path for controlling greenhouse gases” authored by Nordhaus [39] and published in Science, held second place in terms of total citations (228). The author evaluated and compared the five alternative policies toward global warming (No-controls, carbon tax, Stabilize emissions, Stabilize climate and

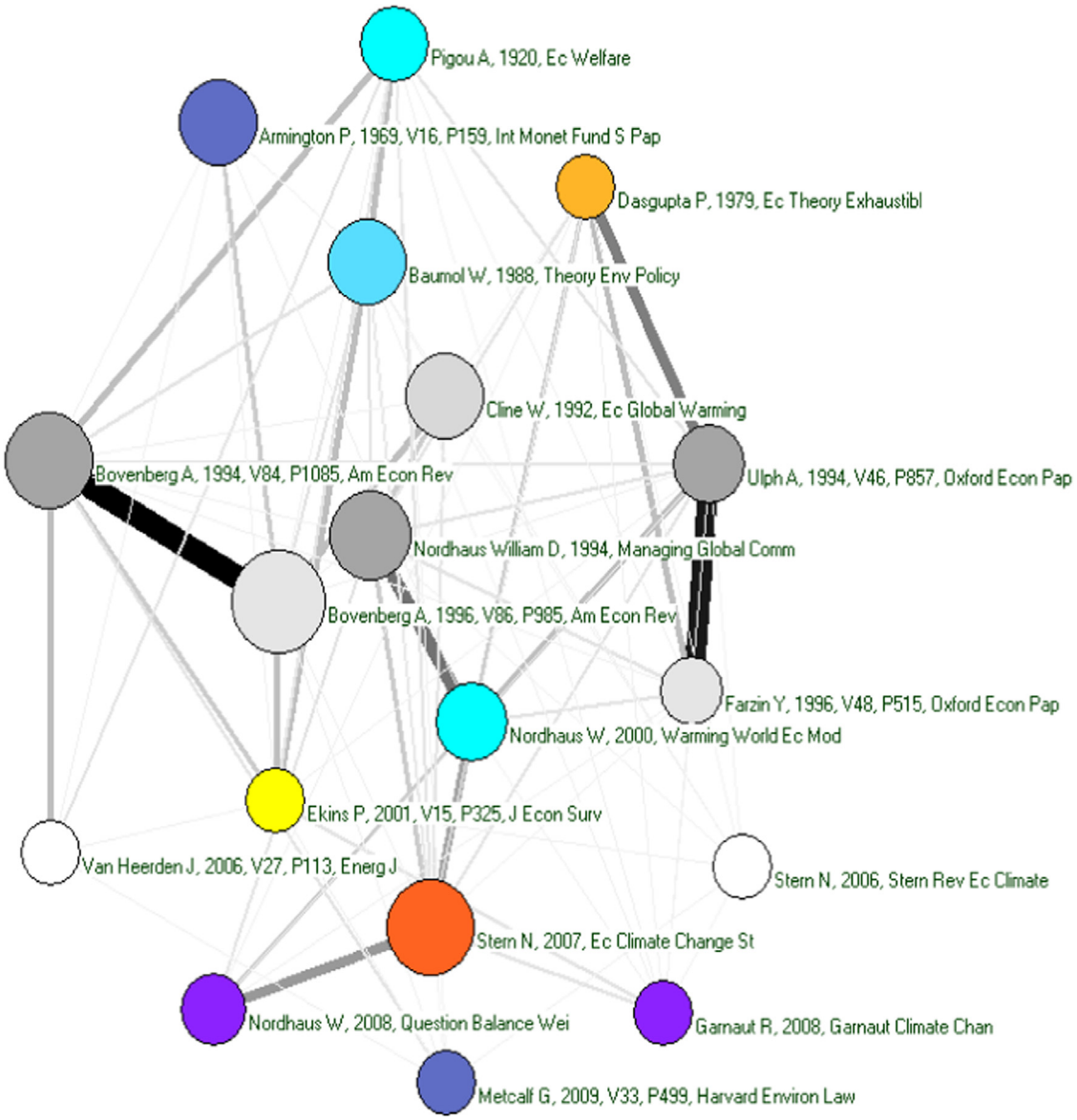

Fig. 8. Association network of the most frequently cited studies.
Note: published year of literature increased gradually from top to bottom.

Table 6
Citation analysis of the publication during 1989–2014.

Title	Journal	Correspondence author	Country	PY	TC	TC/Y
Climate change risk perception and policy preferences: The role of affect, imagery, and values	Climatic Change	Leiserowitz, A	USA	2006	258	25.8
An optimal transition path for controlling greenhouse gases	Science	Nordhaus,WD	USA	1992	228	9.5
Geothermal energy technology and current status: an overview	Renewable & Sustainable Energy Reviews	Barbier, E	Italy	2002	170	12.14
Renewable methane from anaerobic digestion of biomass	Renewable Energy	Chynoweth, DP	USA	2001	132	8.8
Effect of carbon taxes and subsidies on optimal forest rotation age and supply of carbon services	American Journal of Agricultural Economics	Vankooten, GC	Canada	1995	132	6.29
ENTICE: endogenous technological change in the DICE model of global warming	Journal of Environmental Economics and Management	Popp, D	USA	2004	118	9.83
Fair adaptation to climate change	Ecological Economics	Paavola, J	UK	2006	119	11.9
Quantifying the global and distributional aspects of American household carbon footprint	Ecological Economics	Weber, CL	USA	2008	112	14
Energy efficiency-a critical view	Energy	Herring, H	UK	2006	102	10.2
Public policies against global warming: a supply side approach	International Tax and Public Finance	Sinn, HW	Germany	2008	100	12.5

PY=publish year, TC=total citation.
Note: country refers to the country where the first author's institution is located.

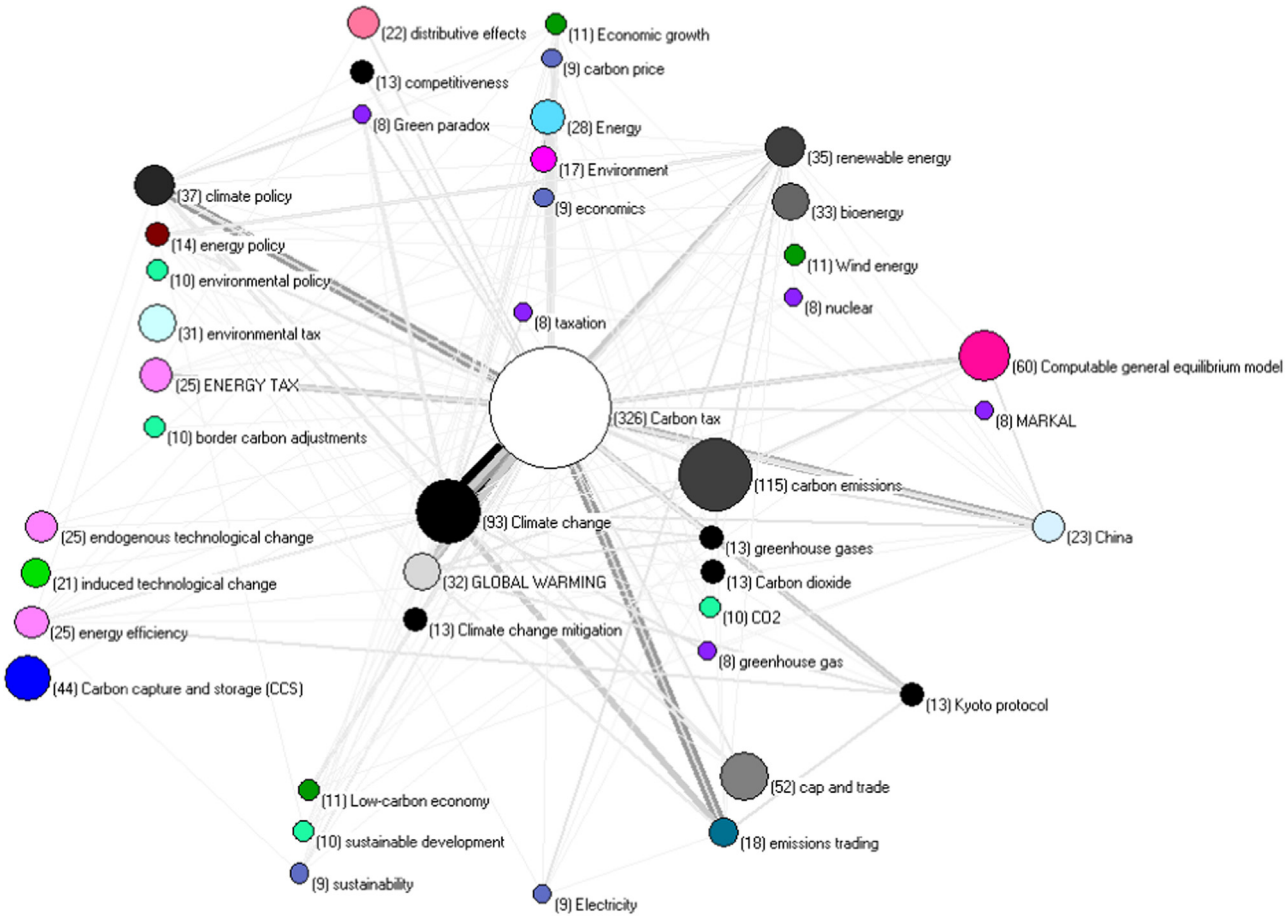

Fig. 9. The co-occurrence network of the high-frequency keywords.

Geoengineering) based on an intertemporal general-equilibrium (DICE) model. In addition, carbon tax literature whose total citations ranked high does not necessary mean that the average annual citations will be high, and vice versa.

3.7. Analysis of research hotspots of carbon tax

As previously stated in Section 2.3, the frequency of keywords in carbon tax publications is employed to reflect the degree of academic concern. The 1224 studies had 4207 keywords, most of which are not frequently employed, whereas there is a small group of keywords that are widely used. After preliminary consolidation of the keywords, the co-occurrence network was drawn around high-frequency keywords (frequency more than 8) in the carbon tax field (Fig. 9).

Based on the keywords frequency results, the research hotspots of carbon tax are as follows:

(1) Climate change and relevant policy: In the context of the "United Nations Framework Convention on Climate Change" and the "Kyoto Protocol", greenhouse gas emissions has become an increasingly core concern of the international community, thereby generating increasingly more policies regarding energy, environment and climate change [40]. Carbon tax is recognized as one of the most cost-effective means of reducing emissions. However, the interactions between carbon tax policy and other policies in an actual implementation are complex and highly uncertain. These policies may complement and reinforce each other; they may also interfere with each other or destroy each other policy' goals [40]. After analyzing the frequency of the keywords, we find that carbon tax is often compared with energy tax and environmental tax. Additionally, border adjustment tax (carbon tariffs) has also received much focus because it will have a great impact on the exports and economies of countries in which it is not mandatory to reduce greenhouse gas emissions.

(2) Carbon emissions trading: under the conditions of perfect competition, perfect information and zero transaction costs, carbon taxes and a carbon emissions trading scheme can substitute for each other if the price or upper limit emissions is set at the balanced point at which the marginal abatement cost equals the marginal revenue. However, the above assumptions are always difficult to satisfy in the real world, and the policy effects of carbon tax often differ from the carbon emissions trading scheme. Therefore, whether to choose the carbon tax or the carbon emissions trading scheme is under debate by researchers and policy makers [41]. There are generally two means by which to compare carbon tax with the carbon emissions trading scheme in current research. One regards the comparative analysis of the carbon emissions-reduction efficiency [42], economic benefits [43], public acceptability [44] and fossil fuel imports [45] between the two policies. The other regards the analysis of the combined effects of the two policies, namely, the emission reduction effect; economic benefits and reduced costs are analyzed based on a mixed climate policy, which is formed after combining the carbon tax policy with the carbon emissions trading scheme policy, in accordance with the applicability and reduction objectives of the two policies [41,46,47].

(3) Socio-economic effects of carbon tax: being a newly introduced distorting tax, carbon tax's potential impact on socio-economic systems has received widespread concern. First, carbon tax will affect the price of related products in the short-run,

thereby affecting the consumption demand and investment. Therefore, whether to tax carbon emissions, what differences exist in the reduction effect under different means of tax rebates and how to reduce the economic impact of the carbon tax have become the focus of governments and scholars' [5,48–51]. Second, a unilateral carbon tax imposed by a country will lead to a country's rising costs of energy-intensive and carbon-intensive industries, and may therefore make it uncompetitive in the domestic and foreign markets. From industrial competitiveness considerations, certain studies have retested the effects of the carbon tax on these industries' international competitiveness and designed measures to mitigate and compensate for the effects [52,53]. Third, because energy intensity differences exist among different industries, and income level differences exist among different income groups, the uneven revenue allocation effects raised by carbon tax has generated widespread concerns. Specifically, these concerns include the direction (progressive or regressive) [54,55], the degree of influence (strong or moderate) [56–58] and the relevant countermeasures [59,60] of the income distribution change in a country or region. Fourth, certain studies have shown that the "double dividend" effect may be generated during the implementation of a carbon tax if the revenue originating from the carbon tax is used to reduce the "distorting incentives" issues of other taxes [61,62]. Finally, the Green Paradox, newly proffered by German scholar Sinn, states that the implementation of measures to mitigate climate change (carbon tax) will reduce the demand of fossil energy (particularly oil); thus, producers will increase the supply of fossil energy in fear of being abandoned in the future energy market. Therefore, the consumption of fossil energy and greenhouse gas emissions will increase, not decrease, which ultimately makes everything regarding emissions reduction measures meaningless [31]. The Green paradox has received broad interest since being proffered, and the existing research mainly focuses on analyzing the theory mechanism of the formation of the "green paradox" from the perspective of carbon tax [63–65].

(4) Renewable energy: because the burning of fossil fuels is an important cause of global climate change, the development of new energy and renewable energy is an important measure to mitigate global climate change [66,67]. Conversely, the implementation of a carbon tax will raise the prices of fossil energy, thus promoting renewable energy alternatives to fossil fuels. Therefore, certain research has compared the differences of the effect between tax incentives (a carbon tax) and regulatory policy (Feed-in tariffs and renewable portfolio standard) on the promotion of renewable energy development [68–70].

(5) Endogenous technological change: technical progress can be reflected in two aspects: one is the improvement of energy efficiency, the other is the induced (endogenous) technological change. Technology change is considered to be an important factor that affects the results in the modeling of climate change policies; therefore, to the methodology for introducing technological change into climate policy models and the interactions between carbon tax and technological change are the focus of modelers. Research in this area can be divided into two categories: the first type is to examine the effect of the endogenous technology mechanisms on the implementation of a carbon tax. One most popular means is to simulate technical progress by increasing the knowledge capital stock that originates from R&D investment [71,72]. In addition, certain studies have simulated technological change through the learning effect of learning-by-doing [73,74]. The second type is to study the influence of carbon tax on technological change and technology diffusion [75,76].

(6) Carbon capture and storage (CCS): CCS technology has attracted much attention because it allows the continued utilization of fossil fuels with a significant reduction in CO_2 emissions [77]. Being a punitive economic measure, carbon tax will increase companies' costs if it is implemented alone; therefore, the companies will ultimately pass on the increased costs to the consumers by raising the market prices of their products. Obviously, this effect is not the original intention of carbon tax [78]. Therefore, there should be certain technical means to support and collaborate with carbon tax during the implementation process. The combination of CCS and carbon tax is one of the measures that have already been extensively studied in carbon tax relevant literature. Certain studies have compared the cost effect of CCS promotion using different incentives measures (carbon taxes, emissions trading system, and carbon capture subsidies) [79,80]. Other studies have compared different policies' effect on carbon emissions, economic output and consumption behavior, such as carbon tax, carbon capture and storage subsidies, and CCS labor subsidies [81]. However, establishing a linkage mechanism consisting of carbon tax and CCS is difficult and involves many social–economic issues, and relevant studies remain comparatively less [77]; therefore, further exploration of the combined use of CCS technology and carbon tax would be an important and interesting research area.

(7) The Computable General Equilibrium (CGE) model is the most frequently used method in the research field of carbon tax. On the one hand, the interactions and feedback among the energy-economy-environment systems form a linkage mechanism. Thus, implementation of the carbon tax policy will not only influence the price and consumption in the economic system, but will also affect the environment and energy systems. On the other hand, the CGE model has a clear neoclassical micro-economic structure, and it can characterize the interaction between the micro- and macrovariables. The main features of a CGE model are that it can simulate the interactions among all subjects in an entire economic system [82]. These characteristics cause the CGE model to meet this demand such that the analysis of carbon tax policy should consider the overall economic system, and certain studies have already applied CGE models to analyze the effect after the implementation of carbon tax both in developed and developing countries [61,83].

4. Conclusions

Based on bibliometrics analysis of carbon tax literature, this paper thoroughly analyzes the development status in the carbon tax field from 1989 to 2014 through social network analysis involving author keywords and references, thereby providing a comprehensive description for the first time. This temporal analysis revealed that scientific productions of the carbon tax field experienced substantial growth in publications, as well as the total citations of documents during the period of 2005–2014. The article was the most frequently used document type, which represented 70.9% of all carbon tax literature. English is the dominant language, as high as 98.7%. At the global level, the USA has been taking a leadership position in carbon tax research with the largest publication as well as a greater academic influence in this field. Furthermore, the carbon tax in China has attracted an increasing level of attention in recent years and was second to the USA in the number of total publications. At the institutional level, the Vrije University Amsterdam was the most productive institution, followed by Massachusetts Institute of Technology, Stanford University and University of Cambridge. Conversely, the collaboration in carbon tax fields at the author, institutional and country levels were all gradually strengthened over time.

This study also determined that the top 20 journals contribute approximately 43% to the total publication of carbon tax literature, in which Energy Policy was the most productive journal followed by Energy Economics, Energy, Applied Energy and Ecological

Economics. Moreover, the carbon tax was an interdisciplinary area because 99 subject categories are involved in this area, and Energy Fuels, Environmental Studies and Environmental Sciences were the top 3 subject categories with the most publications. Conversely, the top two high-yielding authors were TOL RSJ and Gerlagh R, who both are from Netherlands. The analysis of references found that the earliest widely quoted literature related to carbon tax was "welfare economics", written by Pigou in 1920.

The word frequency and co-occurrence analysis of keywords shows that the hot topics in carbon tax field were climate change and relevant policy, carbon emission trading, socio-economic effects of carbon tax, renewable energy, endogenous technological change, as well as carbon capture and storage. In addition, the CGE model is the most widely used model in this field. Recently, the issues regarding whether China will introduce a carbon tax and what potential impacts it will lead to have increasingly received more focus. This study can help to identify the latest research trends in the carbon tax field to offer guidance to future studies in this field.

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