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Expanding and shifting trends in carbon market research: a quantitative bibliometric study

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ABSTRACT

This paper examined the carbon market literature from 1992 to 2011 using bibliometric techniques based on the database of Science Citation Index (SCI) and Social Science Citation Index (SSCI). Of 5809 publications, 82% were journal articles. Our analysis documents that carbon market publications are expanding rapidly. Based on the contribution of countries and their h-index, the US has published most and been most influential in this area, followed by the UK, Canada, Germany and China. The Chinese Academy of Sciences (120), US Forestry Service (70) and University of Maryland (68) were the most productive research institutes. The most common subject category, Environment Sciences (1551), experienced an exponential increase with an average growth rate of about 50%, and the most productive journal was Energy Policy (469). According to the analysis of keywords, the hotspots related to carbon markets were "global warming" and "carbon tax" in the 1990's, but "climate change" and the "clean development mechanism" superceded them in the most recent decade. The most cited article published in Science in carbon market research is presented. This analysis is not only helpful for policymakers and others to understand trends in the field, but may also influence researchers' selection of future studies.

1. Introduction

Climate change triggered by the enhanced greenhouse effect is causing global warming, more severe tropical storms, ocean acidification, melting of glaciers, snow pack, sea ice and sea level rise (IPCC, 2013), and it is one of the greatest threats to human survival and political stability. In 1992, the United Nations Framework Convention on Climate Change (UNFCCC) produced an international treaty focused on stabilizing GHG concentrations in the atmosphere at a level that would "prevent dangerous anthropogenic interference with the climate system". Since then, the 1997 Kyoto Protocol of the UNFCCC was signed by 192 parties with the goal of limiting GHG concentrations in the atmosphere. Since its implementation in 2005, governments have taken measures to mitigate global warming by reducing GHG emissions, thereby reducing damages from climate change (Zhang and Wei, 2010). Three flexibility mechanisms were established with the intention of diminishing the overall cost to achieve emission targets such as the Joint Implementation mechanism (JI), Clean Development mechanism (CDM) and Emissions Trading (ET). The JI aims at carbon emission reduction through the project-based cooperation between developed countries while the CDM enables industrialized countries to reach their individual goals through projects implemented in developing countries. It was designed to allow developed countries with emission caps to offset their carbon emissions by granting carbon removal projects in developing countries (Huisingh et al., 2014). Since 2000, the CDM has allowed crediting of project-based emission reductions in developing countries with over 4000 CDM projects submitted for validation by the end of 2008 and 4626 projects registered by 14 September 2012. There has been rapid growth on the development of CDM in terms of countries involved and scale of emission reductions (Costa-Júnior et al., 2013; Purohit, 2009; Wang and Chen, 2010; Zhao et al., 2013). Given the rising expectations for carbon emission reduction technology as one of the solutions to cope with climate change, an increasingly number of researchers are focusing on different aspects of reaching

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the carbon emission goal. For example, carbon capture and storage (CCS) (Chaudhry et al., 2013; Diamante et al., 2014) helps to prevent the release of large quantities of CO_2 into the atmosphere. In addition, the improvement of energy efficiency (Morrow III et al., 2014) can be achieved by adopting a more efficient technology or production processes; or by applying commonly accepted methods to reduce energy losses; or the substitution of fossil energy with renewable energy resources (Zhao et al., 2011; Zuo and Zhao, 2014; Purohit, 2009). Concern for energy security has also been a motivator for investing in climate change mitigation (Brown and Sovacool, 2011).

Meanwhile, carbon emission trading markets have rapidly developed around the world. For example, the European Commission created the European Union Emission Trading System (EU-ETS) in 2005. EU-ETS has become the largest mechanism for trading carbon emissions in the world (Mizrach, 2012). Although the US and has not ratified the Kyoto Protocol and Australia only became a signatory in 2007, regions and individual states in both countries are participating in emissions trading schemes. In the US, the Regional Greenhouse Gas Initiative (RGGI) was formed in 2003. Participating RGGI states have agreed to establish a cap on emissions of carbon dioxide from power plants, beginning with baseline levels in 2009, and then reduce emissions 10 percent by 2019. According to the National Academy of Sciences (2010), over 50 percent of Americans live in jurisdictions that have enacted a GHG emissions cap or target. In Australia, the New South Wales Greenhouse Gas Abatement Scheme is conducting at the state level and more recently, Australian state premiers have released early proposals for a national cap and trade system starting in 2010 (Anger, 2008). Corresponding to the rapid increasing recognition of carbon market, the associated literatures also spring up substantially (Duic et al., 2003; Lin and Sun, 2010; Zhang and Wei, 2010). Studies of the EU ETS are also increasing progressively (Alberola et al., 2009; Asselt and Biermann, 2007; Reilly and Paltsev, 2005; Skjærseth and Wettestad, 2010).

So far, the operating design mechanism has been regarded as a key feature of carbon markets and has attracted much attention, including the design of allowance allocation and pricing mechanisms (Cramton and Kerr, 2002; Springer, 2003; Zhao et al., 2010). Since the Kyoto Protocol entered into force, the carbon emission allowance has been turned into an international commodity accompanied by an increasing number of investment banks, hedge funds, private equity funds, securities companies, and other financial institutions (Oberndorfer, 2009; Simshauser et al., 2012).

The establishment of carbon emission trading markets is a low-cost marketization measure for reducing GHG emissions in developed countries. Another measure of emission reduction, the carbon tax is also a market-based instrument that depends fundamentally on the efficient working of the market system for its success. In the early 1990's, five European countries (Finland, the Netherlands, Norway, Sweden and Denmark) established carbon taxes, followed by UK which set up the Climate Change Levy in 2001. The Levy raised approximately $1.17 billion in revenues from 2007 to 2009, which were used to offset cuts in National Insurance Contributions. The choice of policy instruments concentrate on uncertainty over prices and quantities. Greater certainty of the economically efficient quantity of pollutant emissions required to internalize social damages favors a cap-and-trade program (Keohane, 2009). Alternatively, pollution taxes may be more desirable if the economically efficient level of the tax is known, or regulators are willing to experiment to explore the efficiency level, (Tietenberg, 2006). An extensive academic literature suggests that macroeconomic efficiency favors a carbon tax with socially productive revenue recycling (Brown et al., 2012; Dinan, 2008). Others have argued that policy choice is less important than the effective policy design (Aldy and Stavins, 2012). Therefore, the discussion and debate between alternative carbon policies is growing (Ekins and Barker, 2001; Ermolieva et al., 2010; He et al., 2012).

With the mitigation of GHGs, the carbon market is gradually maturing in terms of the expanding geographic scope of participating countries, the multi level market structure, and the increasing complexity of financing. This has undoubtedly contributed to the increasing literature on carbon markets, including the review articles (Mansanet-Bataller and Pardo, 2008; Newell et al., 2012; Zhang and Wei, 2010) but rarely quantitative research. Thus, it is time for us to evaluate the growing body of literature on carbon markets by utilizing bibliometric analytical techniques.

The purpose of this study is to quantitatively and qualitatively evaluate the global research literature related to carbon markets from 1992 to 2011. Using bibliometric methods, we can characterize the literature by publication type, subject categories, journals, institutions, countries, citation and content analysis using keywords. In addition, we are able to conduct a detailed analysis of author institution and cited frequency. This study is not only helpful for policymakers and others with interest in carbon market research to assess trends quickly, but may also influence researchers' future studies and publications.

2. Methods

To analyze the trends and characteristics of carbon market research, bibliometric, social network analysis and h-index are valuable. These are introduced below.

2.1. Bibliometric analysis

Bibliometrics, which is a multifaceted endeavor encompassing subareas such as structural, dynamic, evaluative and predictive scientometrics, is one of the rare and interdisciplinary research approaches to extend to almost all scientific fields (Glanzel, 2003). It adopts statistical and mathematical methods to research the distributed architecture, mathematical regularities, varying pattern and quantitative management of the information, and subsequently investigates the structure, characteristics and patterns of the underlying science and technology. As one of the most important methods in the researching of library and information science and a newly developing discipline, the bibliometric technique has become an indispensable instrument for measuring scientific progress (Van Raan, 2005). It is worth noting that bibliometrics is quantitative by nature, but is used to make pronouncements about qualitative features. In fact, this is the major feature of all sorts of bibliometric techniques to transform something intangible (scientific quality) into a manageable entity (Du et al., 2013). The research objects can be all kinds of literatures themselves and the characteristics they reveal include topics, authors, publication dates, reference literatures, content and so on.

2.2. Social network analysis

Social network, which stems from graph theory, is a regulation or a method of analyzing social relations, focusing on the structure of relationships, ranging from casual acquaintance to close bonds (Serrat, 2010). In other words, social network refers to the assemblage of social actors and the relationships between them. It can not only reflect the overall characteristics of the network structure, but also can indicate the correlations among individuals by using quantitative indices to describe interaction relationships among established objects. In this paper, social network analysis was utilized to research the cooperative relationships among 20 productive countries and institutions.

2.3. The impact factor and h-index

The statistical analysis, mainly targeted at published literature and authors, is an essential part of document research. Statistics on the literatures generally cover countries, publishing houses, subjects, languages, journals, research institutions and the number of published articles by different authors. Two measures are used to evaluate the influence: the impact factor (IF) and the h-index.

As one of the most influential tools in modern bibliometrics research and academia, the impact factor was used to assess the carbon market-related journals' relative influence. It is calculated by dividing the number of citations in the JCR year by the total number of articles published in the two previous years (Fu et al., 2010).

The h-index was first proposed by Hirsch to measure the productivity and impact of published works of not only scientists and scholars (Hirsch, 2005), but also research organizations, countries, and journals. It is a good indicator of the impact of a scientist or journal and has the advantage of being objective. It is defined simply as: "A scientist has index *h* if *h* of his/her *Np* papers have at least *h* citations each, and the other (*Np-h*) papers have no more than *h* citations each," where *Np* is the number of papers published over *n* years (Hirsch, 2005). Therefore, the h-index combines a measure of quantity (number of publications) and impact (number of citations) in a single indicator.

3. Results and discussions

At the beginning of the pilot study, "carbon market", or "carbon trad*" or "carbon tax*" as search phrases to search, but too few documents were obtained which may leading to the bad or even wrong research trends. Therefore, to conduct the analysis accurately, almost all relevant words related to carbon market including "carbon market*", or "carbon trad*", or "carbon emission*", or "clean development mechanism*", or "joint implementation*", or "emissions trad*", or "emission allowance*", or "carbon tax*", or "cap-and-trade", or "carbon budget*", or "carbon allowance*", or "carbon permit*", or "carbon econom*", or "carbon asset*", or "carbon finan*", are searched for titles, keywords and abstracts in the database of Science Citation Index(SCI) and the Social Science Citation Index (SSCI) on November 11, 2012. 5809 documents were collected from January 1, 1992 to December 31, 2011. The documents were analyzed according to their type, publication output, general patterns, citation analysis of articles, countries and institutions of publication, and keywords distribution, etc.

3.1. The general patterns

Of the 5809 documents related to carbon market from SCI and SSCI over the past two decades, journal articles account for 81.5% (4735 records), and the rest of the document types include paper proceedings, reviews, meeting abstracts, letters, book chapters, etc. In this paper, only the type of article is considered. As can easily be seen from Fig. 1, both the total number of publications (TP) and the total cited times (TC) had an enormous increase since 1997 when the Kyoto Protocol was signed. However, it is interesting that TP continued to increase after 1997, while TC decreased from over 6000 in 2005 to 2003 in 2011. Due to the increase in TP and the decrease in TC, the annual average citations per year (ACPP) declined from the highest (43.13 times) in 1999 to the lowest (2.35 times) in 2011.

3.2. The subject category distribution

These 4735 articles on carbon markets cover 158 subject categories in SCI and SSCI. The top 8 subjects with the total number and annual number of published articles are shown in Fig. 2. Articles covering Environment Sciences, Environment Studies, and Energy & Fuels hold the top three positions and experienced explosive growth after 2005. It is noteworthy that the growth of Environment Sciences experienced an exponential increase with an average growth rate of about 45%: the average number exceeded 200 after 2009. Ranking fourth, Economics increased in the total publications by an average growth rate of 38% after 2007. Thus, the main research area of carbon market is Environment Sciences and the subject coverage become more and more extensive.

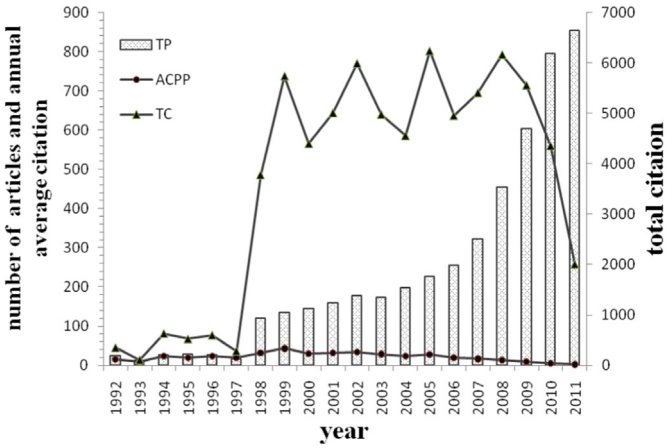

Fig. 1. TP, TC, and ACPP from 1992 to 2011 Note: TP-total number of publications, TC-total cited times, ACPP-average citation per year.

3.3. The performance of journals

A total of 1018 journals published articles associated with carbon markets from 1992 to 2011. Table 1 shows the top 25 journals with 1777 published articles accounting for 37.52% of the total number of articles. Energy Policy took the first place with 469 articles (9.9%), much higher than Climate Policy, the second journal with 125 articles (2.64%). Global Change Biology published 105 papers (2.22%) and its impact factor of 6.862 was considerably higher. Thus, it has had a substantial influence on this research area. Other journals with impact factors higher than 5 were

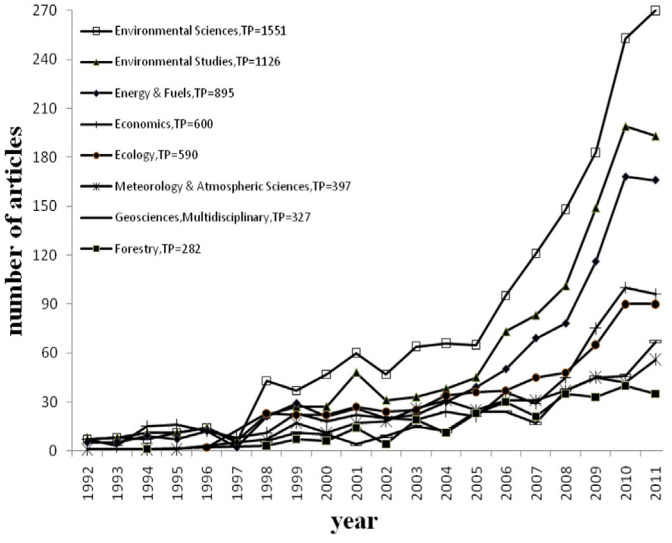

Fig. 2. Number of articles addressing different subjects, 1992 to 2011.

Table 1
The analysis of top 25 journals, 1992–2011.

Journal name	TP	%	IF2012[b]
Energy policy	469	9.90	2.723
Climate policy	125	2.64	1.112[a]
Global change biology	105	2.22	6.862
Ecological economics	92	1.94	2.713
Energy economics	83	1.75	2.344[a]
Forest ecology and management	80	1.69	2.487
Global biogeochemical cycles	66	1.39	4.785
Geophysical research letters	63	1.33	3.792
Climatic change	58	1.22	3.385
Energy journal	54	1.14	2.198
Environmental science & technology	53	1.12	5.228
Bio-geosciences	46	0.97	3.859
Journal of geophysical research-atmospheres	44	0.93	3.021
Energy	43	0.91	3.487
Applied energy	41	0.87	5.106
Journal of geophysical research bio-geosciences	40	0.84	#N/A
Environmental & resource economics	40	0.84	1.523[a]
Agricultural and forest meteorology	38	0.80	3.389
Ecological modeling	37	0.78	2.326
Environmental science & policy	35	0.74	3.024
Journal of environmental economics and management	34	0.72	1.730
Ecological applications	34	0.72	5.102
Proceedings of the National Academy of Sciences of The United States of America	33	0.70	#N/A
Biomass & bio-energy	32	0.68	3.646
Agriculture ecosystems & environment	32	0.68	3.004

TP: the number of total publications; %, ratio of one journal's publications to total number of publications; IF: impact factor; #N/A: Not found.
[a] Data source of: http://wenku.baidu.com/view/f501c5f9910ef12d2af9e78e.html.
[b] Data source: http://www.medsci.cn/sci/.

Environmental Science & Technology, Applied Energy, and Ecological Applications, though they ranked lower in terms of the total number of published articles. Thus, many of these journals achieved high prestige in the carbon market domain.

3.4. An analysis of countries

The contribution of different countries and institutions can be evaluated by analyzing the author's address as it provided the address and affiliations of at least one author. Among the 4735 articles, 79 of them lacked the author address information.

3.4.1. The performance of different countries

From 1992 to 2011, 108 countries have contributed to publishing articles about the research on carbon market indicating that more than a half of the world's 196 countries have scientists who are publishing in the field of carbon market. Of the remaining 4656 articles, 28.65% were internationally collaborative publications and the rest of them were independent publications without any collaboration. Table 2 shows the top ten countries and regions with respect to the number of total published articles, the percentage of single country and internationally collaborated articles along with the article quantity published by the first author's country and the country's h-index.

In these ten high yield countries and regions, five countries were in Europe, two were Asian countries, two were North American and the remaining country is located in Oceania. The most productive country, the US, with 1766 articles accounted for 37.93% following by the UK (689) and Canada (368); the US took the lead whether in terms of the total number publications, single-country publications, internationally collaborative publications, the publications of first author's country or the h-index, underscoring its leadership position in this field again. What is noteworthy is that the number of internationally collaborative publications of each country was higher than their single country publications but almost have the same rank with the total publications. In particular, Sweden ranked 10th in the number of total publications while in terms of the number of internationally collaborative publications it ranked in the 15th place, indicating that its international cooperation should be strengthened. China ranked fifth with a relatively low h-index of 29, indicating that China had a relatively smaller influence in the field.

Table 2
Top 10 productive countries in the publication of carbon market area during 1992–2011.

Country	TP	TP R (%)	SP R (%)	CP R (%)	FP R (%)	h-index
USA	1766	1(37.93)	1(33.11)	1(49.93)	1(30.43)	89
UK	689	2(14.8)	2(11.89)	2(22.04)	2(11.51)	47
Canada	368	3(7.9)	4(4.91)	3(15.37)	3(5.52)	43
Germany	354	4(7.6)	5(4.55)	4(15.22)	5(5.28)	44
China	330	5(7.09)	3(5.48)	6(11.09)	4(5.37)	29
France	257	6(5.52)	8(3.13)	5(11.47)	8(3.59)	33
Australia	253	7(5.43)	6(4.49)	9(7.8)	6(4.15)	25
Japan	234	8(5.03)	7(3.88)	8(7.87)	7(3.82)	25
Netherlands	211	9(4.53)	10(2.23)	7(10.27)	9(2.56)	34
Sweden	150	10(3.22)	9(2.59)	15(4.8)	10(2.41)	26

TP: total publications; SP: single country publications; CP: internationally collaborative publications; FP: publications with first author's country; %, ratio of one country's publications to total number of publications; R: Rank.

Fig. 3 shows the top 5 most productive countries with respect to the time-trend analysis during 1992–2011. It demonstrated that all the countries experienced an increasing trend in the annual number of publications. The US took a significant leading place during the whole period with the total number of publications growing rapidly after 1998 and 2006 due to the promise of the UNFCC in 1997 and the approved Energy Policy Act in 2005.Similarly, the UK pulled away from the other 3 dominant countries with a rapid growth after 2007 as the Climate Change Act came into force in 2008. One could also come to the conclusion from Fig. 3 that China had a similar total number of publications as Canada and Germany, but had a marked increase after 2008, nearly catching up to the UK in recent years.

Bibliometric studies of the energy efficiency and solar energy literatures showed quite different results (Du et al., 2013; Du et al., 2014). While the US has published more than any other country and was also most influential in these areas, other countries were all lagging far behind the US in carbon market area, but nearly close to or even exceed the US in the research of energy efficiency and solar energy in recent years. It should be mentioned that the increasing

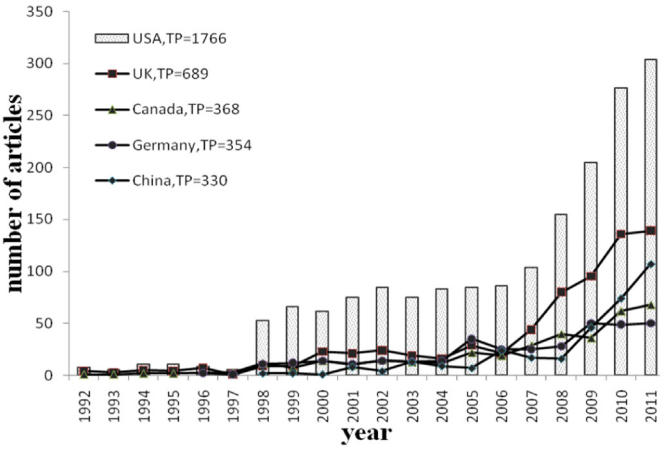

Fig. 3. Annual number of publications by the 8 most productive countries, 1992–2011.

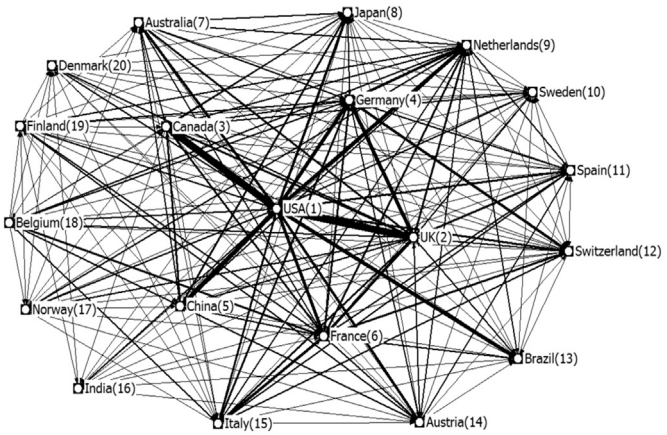

Fig. 4. Collaboration relationships between the 20 most productive countries.

speed of publications in China is much faster than the other countries in the area of energy efficiency and solar energy. In contrast, it is not the case in the area of carbon market, implying that research on carbon market in China has attracted less attention in recent years when comparing to energy efficiency and solar energy.

3.4.2. Cooperation analysis of countries

Based on the social network analysis, the coauthoring relationship among the 20 countries in the field of carbon market was depicted by the cooperation network diagram in Fig. 4. NetDrawing Ucinet software was applied for drawing it on the basis of co-word matrices obtained from bibexcel. The ultimate graph with node points of countries or institutions presented intuitively clear cooperative relationships among them, and the thickness of these connecting lines demonstrated the intensity of cooperation. The thicker the connecting line is, the more frequently the two countries cooperate.

According to the inordinately concentrated thick lines launched from countries, a three-layer network diagram with the US in the center is shown in Fig. 4, documenting that the US has had more frequent cooperation than other countries. Thus, it can easily see thatthe US coauthors frequently with the UK, Canada, China, Germany, Brazil, Japan, Netherlands, and France in order. Besides, close cooperation between the UK and Germany, between Germany and the Netherlands, Switzerland, and Italy, and between France, Switzerland, and Italy can also be seen in the diagram, topping the other countries. It is apparent that China had partnerships with several countries, especially the US and Japan. Note the peripheral location of countries like Denmark with thin or missing lines connecting to other countries because of the limited amount of international publications in the field of carbon market.

3.5. The analysis of institutions

Of the 4656 articles, 43.11% were written by independent institutions, and the rest were coauthored with other institutions. Table 3 describes the ten most productive institutes in carbon market research during 1992–2011.

Among the top 10 institutes, six came from the US and one from China, the UK, Japan and Austria respectively, reiterating the US predominance in research related to carbon market. The Chinese Academy of Sciences ranked first whether in terms of the total publications, single institute publications, internationally collaborative publications or publications of first author's institute; but with respect to the h-index, it only ranked sixth, suggesting a high article-yielding institute with limited influence in this field. The opposite is true for the US Forest Service, which ranked third in terms of total publications, but ranked first with respect to the h-index.

In addition, we analyzed some of the top subordinates of the top three institutions (see Table 4). Of all the subordinates that published more than 10 articles, four were in Chinese Academy of Sciences, two in the US Forestry Service, and only one from the University of Maryland, which shows relatively extensive research related to carbon markets between subordinates of Chinese Academy of Sciences. The analysis of the top subordinates is helpful to learn more about the institutions that have contributed greatly to carbon market research.

The cooperative relationships among the top 20 productive institutes during 1992–2011 were shown in Fig. 5. It can be seen that the closest collaborative relationship exists between the Chinese Academy of Sciences and the National Institute for Environmental Studies of Japan, between Oregon State University and the US Forest Service, and between the National Aeronautics and Space Administration (NASA) and the University of Maryland. Other institutes also had cooperative relations with these 6 institutions indicating a close collaborative relationship in the research field of carbon markets. The peripheral location of institutions with thin or even no lines connecting to other institutions suggests productive opportunities to strengthen international cooperation.

3.6. An analysis of keywords

Statistical analysis of author keywords, keywords plus and title words can be used to identify directions in science, which is proved a useful way to explore the development of science and technology (Garfield, 1990). Of the 4656 articles, 7574 keywords were used, of which 78.3% appeared only once and 10.8% appeared twice. The

Table 3
The 10 most productive institutions, 1992-2011.

Institutes	TP	TP R(%)	SP R (%)	CP R(%)	FP R(%)	h-index
Chinese Academy of Sciences, China	120	1(2.58)	1(1.44)	1(3.44)	1(1.7)	18
US Forestry Service, USA	70	2(1.5)	47(0.3)	3(2.42)	23(0.43)	24
University of Maryland, USA	68	3(1.46)	47(0.3)	4(2.34)	5(0.64)	21
Harvard University, USA	67	4(1.44)	32(0.4)	5(2.23)	6(0.62)	19
University of California, Berkeley, USA	66	5(1.42)	6(0.75)	5(1.93)	3(0.73)	18
University of Oxford, UK	58	6(1.25)	5(0.8)	9(1.59)	3(0.75)	14
National Aeronautics and Space Administration (NASA), USA	52	7(1.12)	131(0.15)	6(1.85)	23(0.43)	23
National Institute for Environmental Studies, Japan	52	7(1.12)	66(0.25)	7(1.77)	10(0.49)	13
Oregon State University, USA	52	7(1.12)	35(0.35)	8(1.7)	9(0.54)	20
International Institute for Applied Systems Analysis, Austria	51	10(1.1)	7(0.75)	11(1.36)	4(0.67)	17

TP: total publications; SP: single institute publications; CP: internationally collaborative publications; FP: publications with first author's institute; %, ratio of one institution's publications to total number of publications; R: Rank.

Table 4
The number by publications in subordinates of the top 3 institutions.[a]

Institution	Subordinate	TP
Chinese Academy of Sciences, China	Graduate University (Graduate School)	38
	Institutional Geographic Sciences & Natural Resources Research	35
	Institute of Atmospheric Physics	11
	Institute of Botany	11
	Institute of Policy & Management	9
	Institute of Applied Ecology	9
US Forestry Service, USA	Rocky Mountain Research Station	14
	Pacific Northwest Research Station	6
	Pacific Southwest Research Station	6
	Fire Science Lab	6
	Southern Research Station	6
	Northern Research Station	6
University of Maryland, USA	Department of Geography	36
	Ctr Environm Sci	6
	School of Public Affairs	5
	School of Public Policy	5
	Earth System Science Interdisciplinary Center	5
	Department of Meteorology	4

[a] The top 6 subordinates of the institutions were selected.

large number of once-only author keywords suggests a lack of continuity and a wide disparity in research (Chuang et al., 2007). Table 5 lists the top fifteen keywords in carbon market research, ranked by usage frequency.

"Climate change", which has consistently been a hot issue over the last two decades, took the first place with 366 articles (10.69%). Meanwhile, "global warming" was a common keyword in these literature, but it has been superseded by the term "climate change", which connotes a broader set of climate perturbations as a result of anthropogenic GHG emissions.

The policy on carbon emission reduction has been one of most important research fields. It is noted that both the "clean development mechanism" and "Kyoto Protocol" did not appear during 1992–1996. However, the total number of articles with these two terms as keywords ranked second and sixth respectively due to the implementation of the Kyoto Protocol by Parties to the United Nations Framework Convention on Climate Change in 1997. By contrast, the ranking of "carbon tax" and "global warming" dropped from the first and second during 1992–1996 to the tenth and fourteenth respectively during 2007–2011. Following an early preference of conducting research on carbon taxes, the CDM, Kyoto Protocol and emissions trading have gained greater prominence in policy-focused published researches.

In addition, a large number of papers play focuses on carbon emission reduction technologies, mainly on carbon capture and storage (CCS), the improvement of energy efficiency, and substitution fossil energy with renewable energy, especially with biomass fuel. This clearly indicates the rapid growth of renewable energy developments with aims on carbon emission reduction.

It is worth noting that "China" was the only country name in the top 15 author keywords. This indicates that the carbon market in China has attracted an increasingly level of attention.

Among the 4735 articles, 1311 papers (accounting for about 25%) have no author keywords. Therefore, keywords derived from cited references named additional keywords, can provide extra information to supplement titles and the author keywords. An analysis of these additional keywords highlight the frequency of four topics: "model", "emissions", "energy", and "dynamics".

3.7. Citation analysis

As the widely used method to examine the citations of frequency, patterns, and graphs in articles and books, citation analysis can establish links to other works or researchers (Garfield, 1983; Leydesdorff and Amsterdamska, 1990; Rubin, 2010). Table 6 showed the most highly cited articles (TI), journal's name (SO), author's name (RP) and country (RP-CC), year (PY), total cites (TC) and average annual citations (TC/Y). Annually variations in the number of citations can trace the impact of publications.

The most highly cited article was entitled "Use of US croplands for biofuels increases greenhouse gases through emissions from land-use change" authored by Timothy Searchinger et al. (2008) and published in Science with 910 total citations and 227.5 annual citations. "Contributions to accelerating atmospheric CO_2 growth from economic activity, carbon intensity, and efficiency of natural sinks" authored by Josep G. Canadellet al. and published in Nature, took the second place in terms of annual citations (86.2).

Of the 11 articles listed in Table 6, five articles (including the two most cited articles) came from the US, underscoring again that the US had a tremendous influence on carbon market research. Four articles were published in Natureand two in Science – two highly influential scientific journals. Simultaneously, we calculated the annual average cited frequency of the enumerated literatures. It

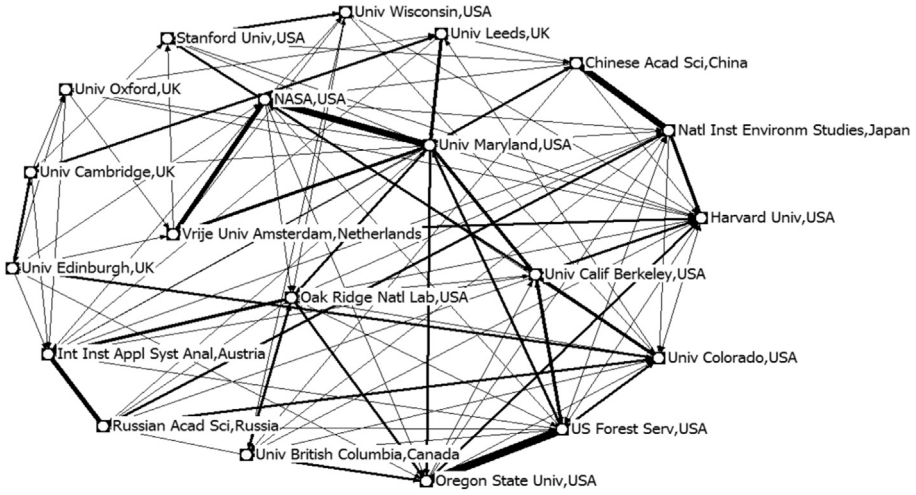

Fig. 5. Collaboration relationships between different institutions.

Table 5
Analysis of the author keywords during the past 20 years (1992–2011).

Author keywords	TP	92–11	92–96	97–01	02–06	07–11
		R (%)	R (%)	R (%)	R (%)	R (%)
Climate change	366	1(10.69)	4(8.47)	2(10.11)	3(7.27)	1(11.94)
Clean development mechanism(s)/CDM	284	2(8.29)	#N/A	3(5.19)	2(7.82)	2(9.16)
Carbon budget(s)/budgeting	215	3(6.28)	25(1.69)	1(12.02)	1(10.7)	5(4.01)
Carbon emission(s)	185	4(5.4)	3(10.17)	12(3.01)	6(5.08)	3(5.77)
Carbon sequestration	160	5(4.67)	25(1.69)	15(1.91)	4(6.86)	4(4.49)
Kyoto Protocol	140	6(4.09)	#N/A	6(4.64)	5(6.04)	6(3.48)
Carbon tax(es)	132	7(3.86)	1(32.2)	8(4.37)	10(3.29)	9(3.22)
Emission(s) trading/trade	127	8(3.71)	25(1.69)	9(4.1)	8(4.39)	6(3.48)
Carbon	112	9(3.27)	#N/A	5(4.92)	9(3.84)	10(2.91)
Carbon dioxide(s)/CO_2	108	10(3.15)	25(1.69)	9(4.1)	7(4.8)	11(2.47)
Climate policy/policies	91	11(2.66)	8(3.39)	25(1.37)	62(0.69)	6(3.48)
Global warming	78	12(2.28)	2(18.64)	13(2.46)	31(1.23)	14(2.16)
China	76	13(2.22)	#N/A	15(1.91)	16(1.92)	12(2.42)
Renewable energy	63	14(1.84)	#N/A	52(0.82)	25(1.37)	13(2.2)
Biomass	61	15(1.78)	25(1.69)	14(2.19)	15(2.06)	20(1.63)

TP: total publications; R (%), the rank and ratio of the number of one period publication to the total publications.

showed that the articles with high average citation were often inconsistent with the high cited articles due to the lag between the original year of publication and subsequent citations.

4. Conclusions

Using bibliometric methods, 5809 publications associated with carbon markets from 1992 to 2011 based on the SCI and SSCI databases were retrieved and 81.5% of which were journal articles. The study reveals that the literature on carbon markets has grown rapidly over the past 20 years. The findings and results are summarized from the following three aspects:

(1) The hottest subject and core journals: Environmental Sciences is the hottest subject experiencing exponential growth with an average increase of about 45% after 2009. Three core journals in carbon market research are also identified: Energy Policy (469 articles), Climate Policy (125 articles) and Global Change Biology (105 articles).

(2) Countries and institutions: The most noteworthy is that the US has played a bellwether role in carbon market research regardless of the total number of articles (1766) or the h-index (89), followed by the UK and Canada. And it also played a key role in the collaboration network of the 20 productive countries. However, through the comparison of the bibliometric studies on "energy efficiency" and "solar energy", the US was not as dominant because of the dispersed regions of publication in those clean energy technology fields. Further, the Chinese Academy of Sciences took first place with the largest number of published articles (120) but relatively low h-index (18) suggesting that its publications in the field of carbon markets had a lower level of influence than those authored by the top the US institutes.

(3) Author keywords and citation analysis: The statistical analysis of author keywords shows that "climate change" and "carbon emissions" remain the focus of carbon market related studies with attentions been paid to carbon emission reduction policies and technologies. Similarly, scholars pay more attention

Table 6
Citation analysis of the publications in carbon dioxide during 1992–2011.

TI	SO	RP	RP-CC	PY	TC	TC/Y
Use of US croplands for biofuels increases greenhouse gases through emissions from land-use change	Science	Searchinger, T	USA	2008	910	227.5
Large-scale impoverishment of Amazonian forests by logging and fire	Nature	Nepstad, DC	USA	1999	559	43.0
Inter-annual variability in global biomass burning emissions from 1997 to 2004	Atmospheric Chemistry And Physics	van der Werf, GR	Netherlands	2006	457	76.2
The US carbon budget: Contributions from land-use change	Science	Houghton, RA	USA	1999	444	34.2
Contributions to accelerating atmospheric CO(2) growth from economic activity, carbon intensity, and efficiency of natural sinks	Proceedings of the National Academy of Sciences of the United States of America	Canadell, JG	Australia	2007	431	86.2
Measurement of emissions from air pollution sources. 2. C-1 through C-30 organic compounds from medium duty diesel trucks	Environmental Science & Technology	Cass, GR	USA	1999	418	32.2
Carbon losses from all soils across England and Wales 1978–2003	Nature	Kirk, GJD	England	2005	359	51.3
Long-term sensitivity of soil carbon turnover to warming	Nature	Knorr, W	Germany	2005	355	50.7
A 70-year retrospective analysis of carbon fluxes in the Canadian forest sector	Ecological Applications	Kurz, WA	Canada	1999	352	27.1
The amount of carbon released from peat and forest fires in Indonesia during 1997	Nature	Page, SE	England	2002	346	34.6
Global warming in the twenty-first century: An alternative scenario	Proceedings of the National Academy of Sciences of the United States of America	Hansen, J	USA	2000	341	28.4

TI: title of articles; SO: the publication journal; RP: correspondence author; RP-CC: country of correspondence author; PY: publish year; TC: total citation; TC/Y: TC/(2012-PY).

to "clean development mechanism" and "climate change" following the signing of the Kyoto Protocol in 1997. On the other hand, the most highly cited article entitled "Use of US croplands for biofuels increases greenhouse gases through emissions from land-use change", authored by Timothy Searchinger, et al. and published in Science had been cited 910 times with an annual average usage frequency of about 227.5.

The study can help policymakers and other who have interest in carbon market research to ascertain general patterns quickly, and may also influence the researchers' selection of future studies as we have presented the main topics and the influential journals for publishing carbon market research. The limitations associated with this study include: (1) Considering the complexity of authors' names, authorship was not analyzed; (2) some information such as number of citation will be changed at different searching time as a result of databases update); (3) the total publication of each institute may be calculated less as its name may have been changed during the study period. Future studies could be conducted to mitigate these limitations.

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