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Review

A bibliometric review on natural resource accounting during 1995–2014

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ABSTRACT

Natural resource accounting plays a critical role in sustainable utilization and conservation of natural resources. This paper aims to review research progress on natural resource accounting for the period of 1995–2014. The main research methods for this study include bibliometric analysis and social network analysis, covering publications' performances, characteristics of related journals, countries, institutions, authors and keywords. The results show that the total amount of publications on natural resource accounting has increased rapidly since 2001. The most productive journal, country, institution, and author are Journal of Environmental Management, USA, University of California, and Dr. Chen, respectively. All of them have higher academic influence. Meanwhile, natural resources that attract most attentions are water and energy. The six main research methods in this field include mathematic modeling, emergy, exergy, ecological footprint (EF), life cycle assessment (LCA) and material flow analysis (MFA).Reasons for the prominent performance of key countries and institutions are then discussed and uncovered, as well as for six methods. Finally, suggestions on how to further promote the development of this research field are raised.

Contents

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1. Introduction

Natural resources play a significant role in supporting modern societies and economic development (Hayha and Franzese, 2014). However, negative relationships between natural resources and economic performances were uncovered in the last century, defined as natural resource curse (Auty, 1994; Frankel, 2012). Most regions with rich natural resources, such as oil and coal, fail to achieve better economic development, due to irrational exploitation and overuse (Behbudi et al., 2010). Although some efforts have been made in order to mitigate such a negative impact by applying advanced technologies and implementing appropriate resource management policies, sustainable utilization of natural resources is yet to be achieved, leading to the depletion of natural resources and corresponding environmental emissions (Iizuka and Katz, 2010; Larson, 2002).

In order to respond such a challenge, both researchers and policy makers have paid increasing attention on effective management of natural resources (Douvere, 2008; Guo et al., 2016; Kellert et al., 2000; Sanders and Masri, 2016; Vacik et al., 2014), especially focusing on natural resource accounting so that the true values of various natural resources can be identified andg more appropriate resource conservation policies can be prepared (Mäler et al., 2008; Williams, 2011; Zhang et al., 2010). In terms of resource types, previous studies found that key resources having direct impact on economic development include water (Chen and Chen, 2016; Ewing et al., 2012), energy (Chen and Chen, 2015; Lei et al., 2010), forest (Campbell and Brown, 2012), land (Alvarenga et al., 2013), and urban ecosystem (Dong et al., 2016), etc. Research hotspots also shifted from pure monetary values to integrated and intrinsic values which consider ecosystem services (Chee, 2004; Fenech et al., 2003; Mellino et al., 2015). Meanwhile, in order to better calculate the values of natural resources, various methods were tested and applied, such as life cycle assessment (LCA) (Koehler, 2008), exergy (Sciubba et al., 2008), ecological footprint (EF) (Hubacek et al., 2009), emergy (Campbell and Brown, 2012), input-output (I/O) analysis (Zhao et al., 2010), material flow analysis (MFA) (Allen, 2008), etc.

However, although many papers have been published in such an important field, few of them summarized the related research progress so that key research topics, methods, authors, institutions can be recognized (Aguinis and Glavas, 2012). Under such a circumstance, it is necessary to review all the related literature on natural resource accounting. This paper aims to fill such a research gap by conducting a bibliometric analysis. Such a method has been widely accepted for offering innovative perspectives on evaluating research trends through citation analysis and content analysis (Mao et al., 2015). In addition, in order to present a good visualization effect and concise expression, social network analysis (SNA) is employed (Zhuang et al., 2013). The research period is from 1995 to 2014 due to the rapid evolution and increasing concerns on natural resource accounting during this period. Various features on all the related publications are analyzed, including publication types, major journals, key countries, institutions and authors. Moreover, word cluster analysis is undertaken in order to classify topics in terms of keywords.

The whole paper is organized as below. After this introduction, major research methods are described in Section 2. Then, analysis results and discussions are presented in Section 3 and Section 4, respectively. Finally, Section 5 draws research conclusions.

2. Methods and data

2.1. The bibliometric method

Bibliometric analysis is an effective method to quantitatively analyze academic publications using statistical techniques (Zhang et al., 2015). It has become a common tool of systematic analysis in various disciplines of science and engineering, which aims at evaluating the research status and trends of a given topic, as well as identifying future research directions to guide younger researchers (Fu et al., 2010). Bibliometric analysis investigates scientific publications through a series of procedures, such as publication outputs of different journals, countries, institutions, authors and citation analysis, and identifies pathways that centered more on content analysis and research evolution (Liu et al., 2011).

Two indicators, namely impact factor (IF) and h-index, are closely related with bibliometric analysis. IF is a standardized indicator to evaluate the quality of a journal, which is created by the Institute of Scientific Information (ISI) according to one journal's citations and publications in the last two years (Buela-Casal and Zych, 2012; Garfield, 2006). A higher IF usually reflects higher quality of one journal although some arguments on this indicator do exist. h-index means that h of one's total articles are cited at least h times (Hirsch, 2005; Hirsch and Buela-Casal, 2014). It is an objective indicator considering both quantity and quality of one scientist (Alonso et al., 2009) and has been widely used to evaluate a journal or a country's academic level (Bornmann et al., 2011). Similar to IF, a higher value of h-index usually reflects a higher scientific achievement.

Also, in order to facilitate the bibliometric analysis, the bibexcel software was utilized. It can extract basic information of each searched article, including the authors' information (names, countries, and institutions), publication year and journal, total citation times, and keywords, facilitating detailed analysis on key features of related research outcomes.

2.2. Social network analysis (SNA)

SNA method is a visual way to analyze the connections between actors, e.g. people or groups, which could reflect the centrality of the actors and the intensity strength of relationships among them from a statistical perspective (Newman, 2001). In the network graph, actors and relationships are represented by weighted nodes and edges, respectively (Ye et al., 2012). Due to the development of network theory and software tools, SNA has been widely utilized to measure research collaboration in various fields so that the contributions from different countries, institutions and scientists can be evaluated. (Nunkoo et al., 2013). The frequently used visualized software for SNA include Pajek, Gephi, and UCINET, (Stieglitz and Linh, 2012).

In this study, SNA was used to evaluate academic collaboration among different countries and authors through the application of Gephi. There are two steps for SNA. The first one is information extraction, which means that country information of each author in each article was extracted by using bibexcel so that the visualization effect of academic cooperation among different countries can be presented. The second step is to draw a cooperation diagram with the input data from bibexcel by using Gephi.

2.3. Data collection

Due to the popular use of Scopus in the academic world, Scopus was selected as the key database for this study. “Natural resource accounting” and “natural resource calculation” were chosen as the keywords to search publications published during 1995–2014. Totally, 3201 publications were found, including research articles (66.64%), conference papers (24.02%), review papers (4.78%), book chapters (1.47%), and other publications. In terms of publication language, English is the most frequently used (89.47%), followed by Chinese (6.90%), Russian (0.91%), etc.

Since English is the most commonly used academic language, 2649 English language publications were reserved, covering research articles, conference papers and review papers, but not other types of English publications.

3. Results

3.1. The performances of selected publications

As shown in Fig. 1, the number of annual publications (NO.) had gradually increased during 1995–2014. The annual total citations (TC) fluctuated with three peaks occurred in 2002, 2007 and 2009 respectively, and then decreased gradually during 2011–2014. The annual average citations had increased from 1995 to 2002 and then decreased gradually since 2002.

3.2. The performances of different journals

Table 1 lists the top 10 most productive journals in such a field. These top journals only account for 16.0% of the total investigated publications, implying diversified distribution of these publications and a broad interest in natural resource accounting from multiple perspectives. Journal of Environmental Management is the dominate journal in such a field, with the highest *h*-index but an ordinary IF. Other dominating journals include Environmental Management, Environmental Science & Technology. Interestingly, the causality among three indicators (total published papers in one journal, IF and *h*-index) is not found in such a field. This may be caused by the fact that IF and *h*-index reflect both quantity and quality of publications that one journal published, while total published papers in one journal entirely depends on the quantity of publications. Most journals with higher reputation actually cover many research fields, in which natural resource accounting is just one of them.

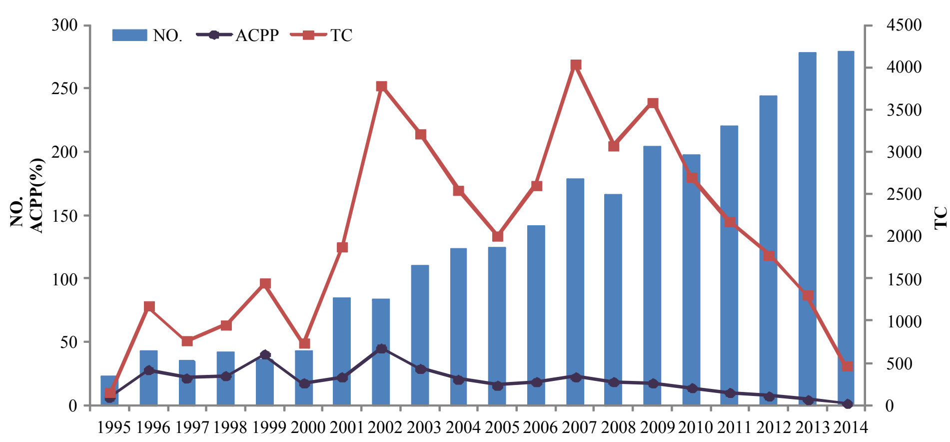

Fig. 1. The performance of selected publications.

Table 1
The performance of top 10 most productive journals.

Journal names	TP[a]	%(R)[b]	IF[c]	*h*-index (R[d])
Journal of Environmental Management	76	2.87 (1)	2.723	23 (2)
Environmental Management	61	2.30 (2)	1.724	20 (3)
Environmental Science and Technology	50	1.89 (3)	5.33	27 (1)
PLoS ONE	44	1.66 (4)	3.234	9 (19)
Ecological Economics	40	1.51 (5)	2.72	19 (4)
Environmental Monitoring and Assessment	34	1.28 (6)	1.679	13 (7)
Water Science and Technology	32	1.21 (7)	1.106	10 (17)
Science of the Total Environment	31	1.17 (8)	4.099	11 (13)
Conservation Biology	29	1.09 (9)	4.165	12 (8)
Ecological Applications	26	0.98 (10)	4.093	16 (5)

[a] TP: The total publications of the journal during 1995–2014.
[b] %(R): The percentage of the total publications of the journal and its rank.
[c] IF: The journal's impact factor in 2014.
[d] R: Rank of the journal's *h*-index in the data set established by this paper.

3.3. Publication features of different countries

3.3.1. Countries' performances

As shown in Table 2, the USA is the most productive country in such a field, accounting for 34.43% of 2580 publications by tracking authors' addresses. China is the second most productive country, but with a big gap to USA. Other productive countries include UK, Canada, Australia, Germany, Italy, France, Japan and Spain. All of these countries are major manufacturing countries in the world, reflecting that manufacturing countries usually consume more natural resources and pay more attention on accounting natural resources. Also, except China, those native English speaking countries have better performances because the authors in these countries have better skills and channels to publish their research outcomes in English language journals or conference proceedings. Another key feature is that among the top productive countries, China is the one with least international collaboration, indicating that China should support their scholars to further engage in international collaboration.

Fig. 2 shows the annual publication numbers of the top 5 productive countries. The USA is always the No.1 productive country for the period of 1995–2014. China has experienced a sharp increase and become the 2nd productive country since 2006, indicating its increasing attentions on natural resource accounting due to its increasing demand on natural resources. Actually, China has become a key country to import natural resources, such as iron ore, coal, crude oil, wood, etc, since its domestic natural resources cannot meet with the soaring demand of manufacturers.

Table 2
The performance of top 10 most productive countries.

Country	TP [a]	%(R)[b]	SP %(R)[c]	CP %(R)[d]	C (%)[e]	*h*-index (R[f])
USA	912	34.43 (1)	24.92 (1)	10.43 (1)	29.50	68 (1)
China	309	11.66 (2)	10.58 (2)	1.40 (10)	11.65	26 (5)
UK	165	6.23 (3)	3.26 (6)	3.14 (2)	49.09	33 (2)
Canada	155	5.85 (4)	3.95 (3)	2.05 (5)	34.19	23 (8)
Australia	149	5.62 (5)	3.37 (5)	2.40 (4)	41.61	30 (3)
Germany	134	5.06 (6)	2.56 (7)	2.64 (3)	50.75	27 (4)
Italy	132	4.98 (7)	3.45 (4)	1.67 (8)	32.58	25 (6)
France	84	3.17 (8)	1.28 (12)	1.98 (6)	60.71	20 (11)
Japan	75	2.83 (9)	2.02 (8)	0.89 (13)	30.67	16 (13)
Spain	72	2.72 (10)	1.51 (10)	1.28 (11)	45.83	19 (12)

[a] TP: The total publications of one country during 1995–2014.
[b] %(R): The percentage of the total publications of the country and its rank.
[c] SP %(R): The percentage of publications and its rank without international collaborations.
[d] CP %(R): The percentage of publications and its rank with international collaborations.
[e] C (%): The percentage of the international collaborative publications of one country.
[f] R: The rank of the country's *h*-index in the data set established by this paper.

3.3.2. Academic cooperation

Fig. 3 shows the academic collaboration among the top 20 most productive countries. The size of one circle stands for the total publication number of one country through international collaboration. The bigger the circle, the more internationally active the country is. The width of the line between two countries refers to the collaborative frequency. A thicker line corresponds to a closer relationship. As shown in Fig. 3, the USA is the most active country in terms of international collaboration, especially, with UK, China, Canada, Germany, Australia and Italy, with 35, 31, 28, 27, 24 and 21 cooperative publications, respectively. In addition, UK and Germany are also active in this respect. The main reason is probably that both USA and UK are English speaking countries and have

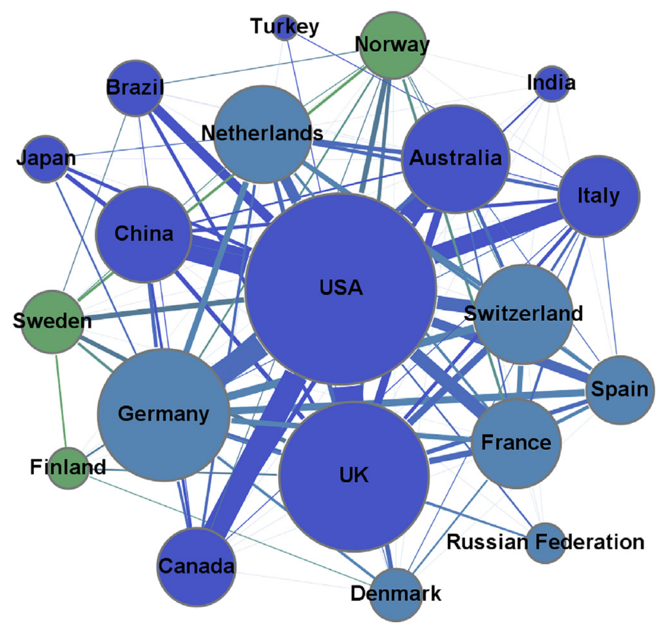

Fig. 3. The academic collaborative relationships among the top 20 most productive countries.

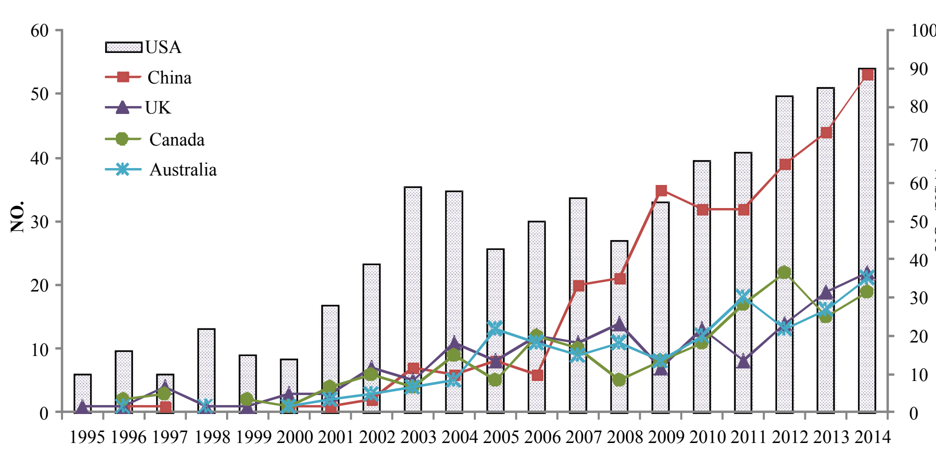

Fig. 2. The growth trends of the five most productive countries.

many outstanding scholars, while Germany is a famous research country and also a key manufacturing country with a huge demand on natural resources. In addition, traditionally these countries are familiar with international collaboration and regard it as a key research strategy.

3.4. Institutions' performances

The performance of top 10 most productive institutions is shown in Table 3. Most of them are from top 5 productive countries. University of California is the leading research organization in such a field with the most publications, collaborations and a highest *h*-index, followed by Chinese Academy of Sciences and University of Siena. In general, China is the only developing country to have research institutions listed in the top 10 most productive institutions. It indicates that Chinese institutions pay a lot of attentions in such a field, due to the great demand of natural resources for its rapid development. Also, both Australia and Canada are resource-rich countries and rely on exporting natural resources to other countries, thus, it is not surprised to have two institutions from each country to be listed as the top 10 most productive institutes.

3.5. The features of authors

3.5.1. Authors' performances

Fig. 4 shows the total publications and *h*-indexes of the top 16 most productive authors, with at least 8 publications but at most 13 publications. Among these authors, nearly one third do not belong to the top 10 most productive countries, indicating that authors from other less productive countries also have better productivity in such a field. However, almost all the authors are listed under the dash line in Fig. 4, which means relatively poor academic quality comparing with the publishing quantity. For this figure, if one author is closer to the dash line, then he/she should have a better academic performance. Thus, it is clear that Drs. Wackernagel, Ulgiati and Schandl have higher scientific quality among all the listed authors. From *h*-index point of view, Dr. Bakshi is the top author, indicating his better academic performance and more of his papers are widely recognized. Dr. Chen is the most productive author with the most publications. But his *h*-index is relatively low, indicating that his publications did not receive enough citations.

3.5.2. Co-authorship performances

Fig. 5 presents the academic cooperation among the active authors in the research area of natural resource accounting. 6 most active research groups were shown according to their academic

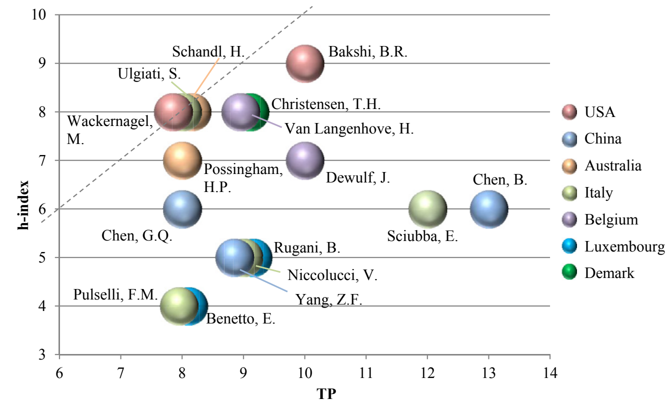

Fig. 4. The performances of top 16 most productive authors.

collaborative relationships. The largest author node belongs to Dr. Chen from Beijing Normal University, focusing on urban ecosystem by employing exergy and emergy analysis. This cooperative cluster is linked with two other clusters through Dr. Enrico. One cluster combined exergy and LCA to study resource consumption, represented by Bhavik and Dewulf. And the other cluster (centralized by Drs. Benedetto and Valentina) engaged in ecosystem goods and services, water resource and regional ecosystem by combining emergy, LCA and EF analysis. In addition, the three smaller clusters, centered by Dr. Ulgiati, Valero and Schandl, applied emergy, exergy and MFA to analyze ecosystems, mineral resources and resource usage, respectively.

3.6. The features of keywords

3.6.1. Keywords' performances

Keywords represent the main research foci of one article and can help readers recognize the key research contents of one article. Keywords analysis was conducted to reveal the hot issues and research trends of natural resources accounting. As illustrated in Fig. 6, most keywords appear only once, accounting for 84.7% of the total 6743 keywords. So many keywords indicate the more diversified studies in this field. In order to improve the effectiveness of keywords analysis, all the raw data were pre-treated so that keywords with similar meanings are represented by one unified word. For example, the treated "emergy" represents "emergy analysis", "emergy evaluation" and "emergy accounting". After such a treatment, only 2511 keywords are left.

Table 3
The performance of top 10 most productive institutions.

Institute	Country	TP [a]	%(R)[b]	SP %(R)[c]	CP %(R)[d]	C (%)[e]	*h*-index (R[f])
University of California	USA	52	2.02 (1)	0.43 (2)	1.59 (2)	38.46	21 (1)
Chinese Academy of Sciences	China	52	2.02 (1)	0.39 (4)	1.63 (1)	19.23	16 (2)
University of Siena	Italy	28	1.09 (3)	0.50 (1)	0.58 (4)	21.43	12 (3)
Beijing Normal University	China	24	0.93 (4)	0.43 (3)	0.50 (7)	29.17	8 (13)
United States Geological Survey	USA	21	0.81 (5)	0.39 (5)	0.43 (12)	9.52	7 (18)
University of Queensland	Australia	21	0.81 (5)	0.19 (12)	0.62 (3)	47.62	12 (3)
University of British Columbia	Canada	20	0.78 (7)	0.31 (6)	0.47 (10)	45.00	8 (13)
Peking University	China	20	0.78 (7)	0.27 (8)	0.50 (8)	25.00	11 (6)
University of Melbourne	Australia	18	0.70 (9)	0.12 (18)	0.58 (5)	44.44	11 (6)
Mcgill University	Canada	17	0.66 (10)	0.23 (10)	0.43 (13)	47.06	7 (18)

[a] TP: The total publications of one institute during 1995–2014.
[b] %(R): The percentage of the total publications of the institute and its rank.
[c] SP %(R): The percentage of publications and its rank of single institute publications.
[d] CP %(R): The percentage of publications and its rank with collaborations.
[e] C (%): The percentage of the international collaborative publications of one institute.
[f] R: The rank of the institute's *h*-index in the data set established by this paper.

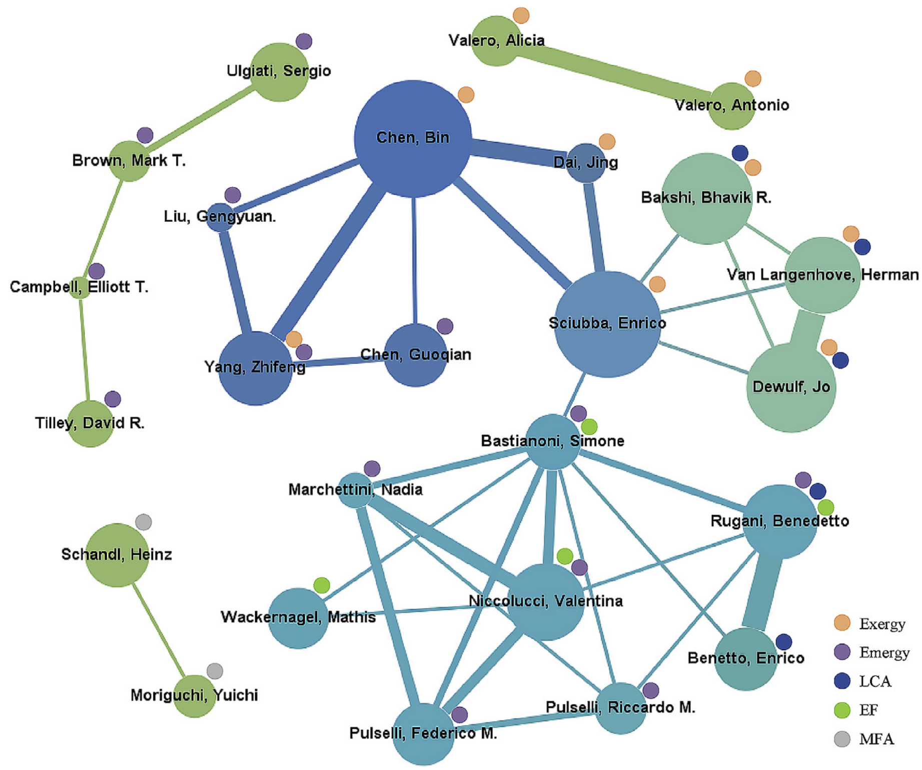

Fig. 5. The network of co-authorship and authors' research methodology.

The classification of keywords is shown in Fig. 7. Almost half of classified keywords focus on research objects, while other keywords focus on research methods and other fields. In terms of research objects, water and energy receive most attentions due to the large consumption and indispensable demands by human society. In terms of water resource, 52.4% of water-related articles investigated specific types of water resource, in which the top five types include groundwater, river, water, wastewater and stream. Similarly, 69.3% of energy-related articles investigated 11 types of energy resources. Renewable energy sources, such as wind, solar and biomass, receive more attentions, while natural gas and oil, as the widely used fossil fuels, are also intensively studied. In terms of research methods, mathematical modeling is the most traditional and popular one. Similarly, emergy, exergy, EF, LCA and MFA are gradually accepted and widely employed to account natural resources. Other keywords mainly present the research orientations, such as indicators, sustainability, climate change, etc. These keywords can help readers better understand the key topics of one article.

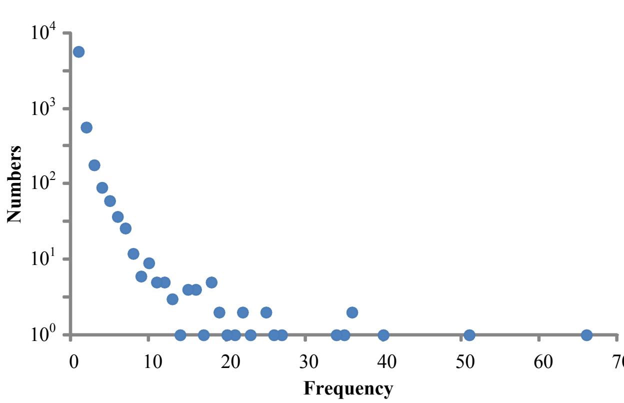

Fig. 6. Frequency of keywords.

3.6.2. Features of natural resources

Fig. 8 shows the study trends of primary natural resources in the top 5 most productive countries. It is clear that both water and energy are always the vital natural resources in these five countries. However, comparing with water, energy had received more attentions during this period in UK and Canada. Also, land is the third natural resource attracting all the five countries although with much less attentions than water and energy. In addition, forest and waste had been investigated due to their increasing significance. China paid more attentions on investigating urban ecosystem due to its rapid urbanization and economic development, while other four countries had less attention on this field due to their mature urbanization.

3.6.3. Features of research methods

As the main methods in the field of natural resource accounting, mathematic modeling, emergy, exergy, EF, LCA and MFA are further analyzed. Fig. 9 shows the publication numbers and the corresponding application ratios of these methods within an interval of five years. The application of mathematical modeling increased quickly and became the leading one among all the methods although its percentage in the total selected publications decreased gradually. Correspondingly, the percentages of applying other five methods increased, indicating the diversity and development of various methods in this field. Among these five emerging methods, emergy received more attentions, followed by LCA, EF and exergy, while MFA is the only one with a decreased number in the last five years.

Fig. 10 shows the combination among the six main methods. The

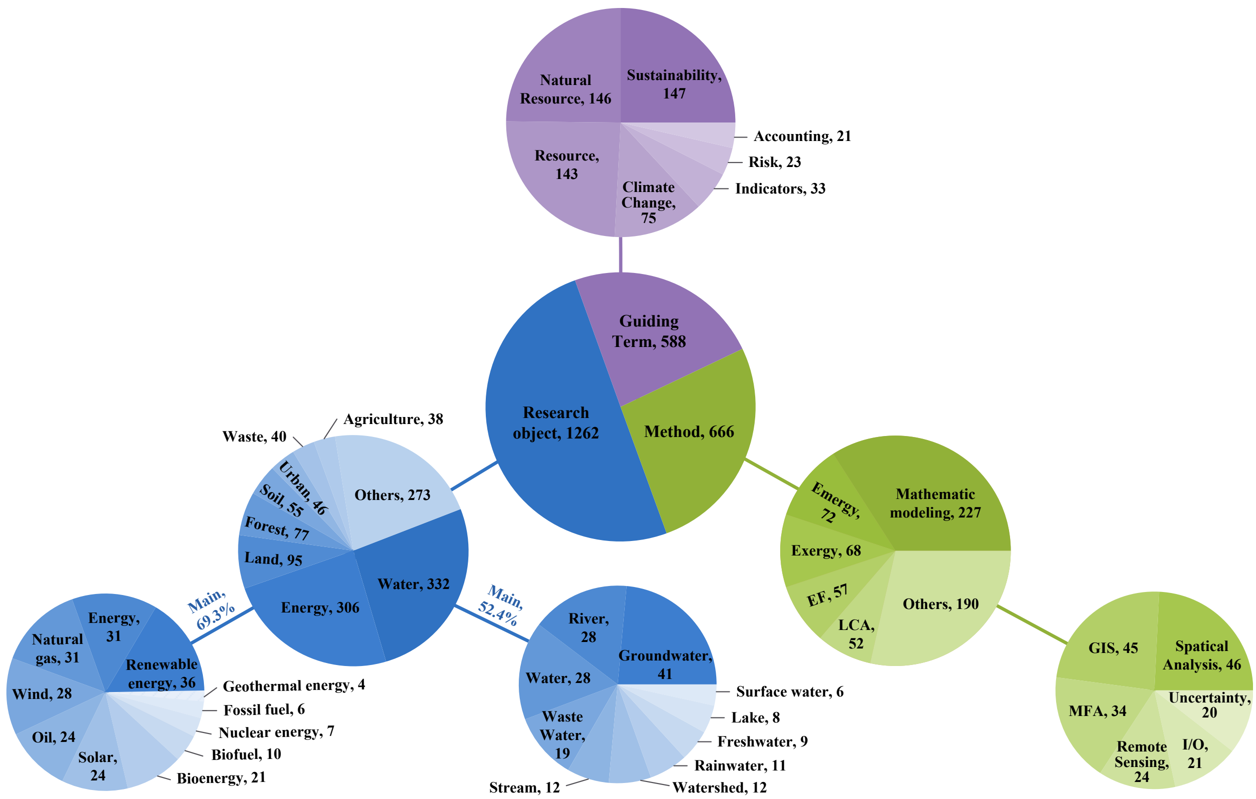

Fig. 7. The classification of main research foci.

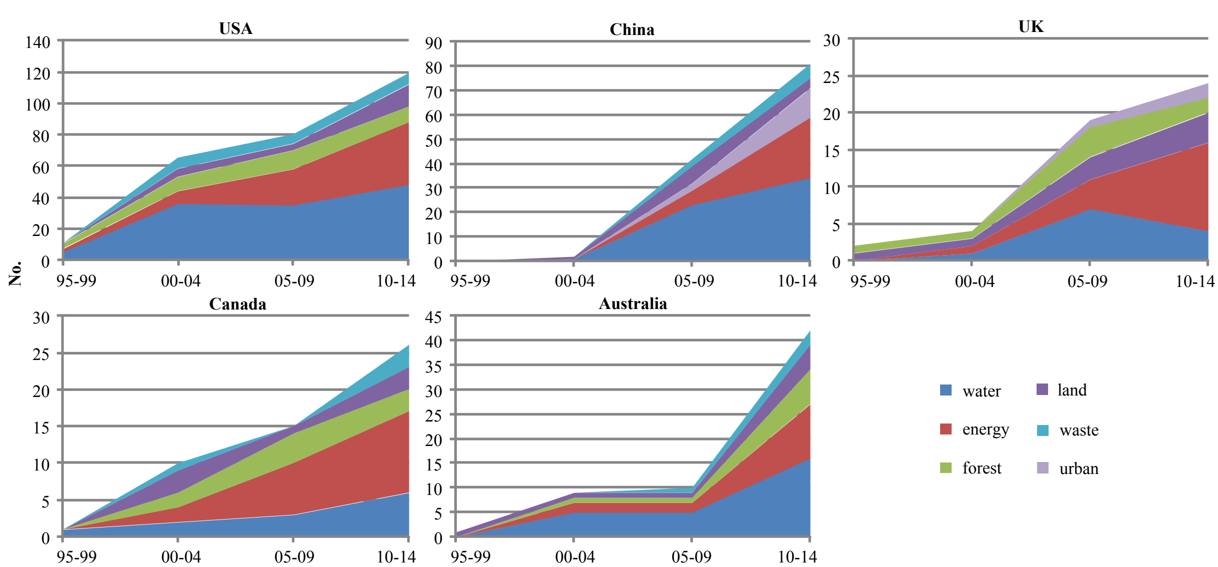

Fig. 8. The development of the natural resource accounting in the top 5 most productive countries.

size of each circle represents the publication number s with combined research methods. The width and color of one line represent the combination frequency and time between the two methods, respectively. In general, most method combination happened in the second decade of the investigated period. Emergy is the most favored method and can be easily combined with other methods. Particularly, this method can combine with LCA, EF, exergy, or mathematic modeling to study the value of natural resources, especially in the last five years. Some researchers also tried to link LCA with exergy. Meanwhile, few articles combined three different methods. For instance, Hoang (2014) integrated emergy, exergy and MFA to quantify resource efficiency.

4. Discussions

4.1. Two outstanding countries

The total publications of the top 10 most productive countries account for 82.6% of the total investigated publications, reflecting their prominent interests on natural resources accounting. Among

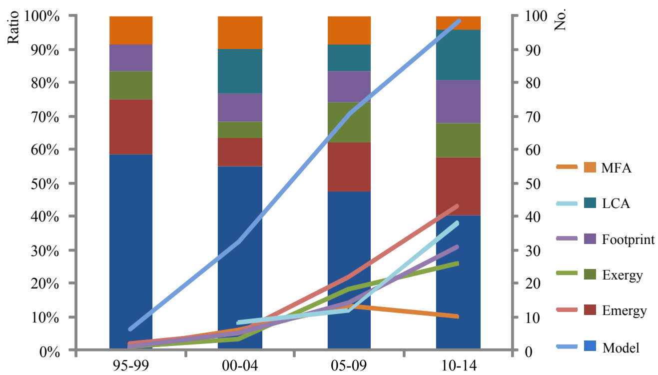

Fig. 9. The development of six main methods.

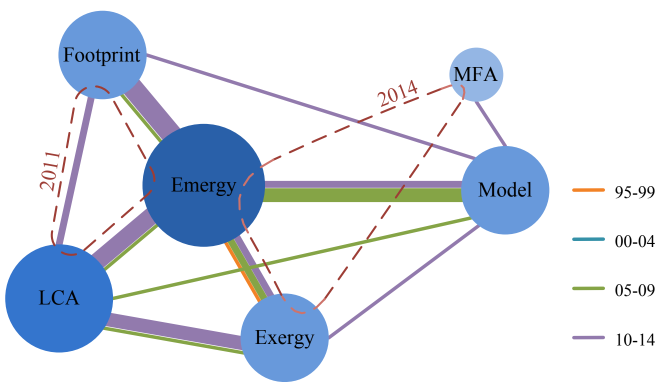

Fig. 10. The combinations between six main methods.

them, the USA is the most influential one with the most publications, international cooperation and diversified research directions. Also, the most productive institution and the most prestigious author with the highest academic influence are both from USA. USA is the largest developed country and consumes more natural resources. USA is always paying attentions on natural resources and has invested a lot of research money on supporting natural resources accounting. There are four major academic funding systems, including government, universities, enterprises and non-forprofit organizations (Jian, 2006). They are independent in nature, but with frequent cooperation. Such a flexible funding system can guarantee that researchers would receive adequate research funds to carry out their studies and promote academic information sharing and exchanges (Etzkowitz and Leydesdorff, 2000). Also, USA is an English speaking country and their researchers can easily publish their research outcomes in English language journals.

The second productive country is China. Its total publications on natural resources accounting increased rapidly in the last decade. Also, three of the top most productive institutions and the most productive author are from China. This echoes the fact that the Chinese government is paying more attentions on natural resources. On one hand, as the world factory, China is producing commodities for the whole world and consumes a lot of natural resources. The domestic supply cannot meet with the increasing demand, leading to increasing natural resources import from many other countries. On the other hand, the corresponding environmental emissions from the consumption of natural resources have resulted in degraded ecosystem services, air and water pollution, soil contamination and more public health concerns. In order to respond such a challenge, China has released many regulations, such as cleaner production promotion law in 2003 (Geng et al., 2010), circular economy promotion law in 2009 (Geng et al., 2012), and ecological civilization strategy in 2014 (Geng et al., 2016). With the implementation of these regulations, several pilot projects on incorporating natural capitals accounting into officials performance evaluation have been initiated, providing more research needs to the Chinese academia (Sun et al., 2016; Xinhuanet, 2015). However, due to the lack of English presentation ability and international collaboration, the academic influence in China in such a research field is still weak, leading to the need to further improve research quality through international collaboration.

4.2. The top 10 most productive institutions

Among the top 10 most productive institutions, nine are universities, the other one is United States Geological Survey (USGS), a scientific research institution affiliated with the USA government. Different from universities, USGS has clear research targets and devote to serve the needs of governments at different levels. Most of their publications are finished independently and have relatively lower academic influence (shown in Table 3). In comparison, universities have more freedom to choose research fields and encourage their professors and students to publish their papers in the highly recognized academic journals. For instance, as the world's top productive university in such a field, University of California conducted many cutting-edge studies with adequate project funds and more international collaboration. All the top 10 most productive institutions are from USA, China, Canada and Australia, reflecting that countries with larger territories usually pay more attentions on natural resources accounting. All of them have abundant natural resources and rely on natural resources for their economic development. However, Russia and Brazil are also large countries in terms of territory. Both of them have large reserves of natural resources and their economy relies on natural resources, but with less publications. One reason is probably that both countries are not English speaking countries and their researchers are not good at presenting their research outcomes in English language journals. But the main reason is probably that both national governments do not pay enough attentions on this field and their research institutions are not sufficiently supported. Consequently, more productive countries and institutions should initiate more international collaboration with their counterparts in both Russia and Brazil, as well as in many other resource-rich countries, so that sustainable natural resources utilization can be achieved globally.

4.3. Research evolution and features of six main methods

Mathematic modeling, emergy, exergy, EF, LCA and MFA are mainstream methods on natural resource accounting. Table 4 presents their evolution process and features. These six methods could be classified into two types according to their features. One is economic type (mathematic modeling) since it focuses on monetary value of natural resources which could be easily understood by policy makers. Mathematic modeling approach has been the dominating research method since it can provide quantitative information to support scientific decisions through optimizing the allocation of natural resources. However, the anthropocentric studies always partly ignore or underestimate the true value of natural resources (Campbell and Brown, 2012). This induced the rapid development of other eco-centric methods, such as emergy, exergy and EF. These methods can be regarded as environmental type (including emergy, exergy, EF, LCA and MFA) that has potentials to address the problem. It emphasizes natural consumption and environmental impacts from physical perspectives. Particularly, due to the fact that emergy (the sum of all available energy inputs directly or indirectly required by a process to generate a product) can assign values to nature's environmental effort and investment (e.g., solar, deep geothermal heat, and gravity) to make and support flows, materials, and services and to contribute to the economic system, it has been graduated accepted for accounting natural resources (Brown and Ulgiati, 2004; Brown et al., 2010; Geng et al., 2013; Yu et al., 2016). Similarly, MFA has been popular since it can quantify flows and stocks of materials or substances in a well-defined system and therefore is an important tool to study the bio-physical aspects of human activity on different spatial and temporal scales. It is considered a core method of natural resources accounting and can measure mass degradation in a process. Practically, two notable milestones on MFA include the establishment of ConAccount network by European Commission and the publication of first methodological guide by Eurostat (Fischer-Kowalski et al., 2011).

In addition, these six methods could be classified into two types according to their features. One is economic type (mathematic modeling) since it focuses on monetary value of natural resources which could be easily understood by policy makers. However, the anthropocentric studies always partly ignore or underestimate the true value of natural resources (Campbell and Brown, 2012). The other one is environmental type (including emergy, exergy, EF, LCA and MFA) that has potentials to address the problem. It emphasizes natural consumption and environmental impacts from physical perspectives. For instance, all flows are converted into one unified unit (solar energy) in the emergy analysis (Ulgiati and Brown, 2009). Similarly, the commensuration of EF is land area (Wackernagel et al., 1999), and MFA measures material mass degradation (Hendriks et al., 2000). The five environmental approaches provide new perspectives to evaluate the relationship between ecosystem and human society and assess the sustainability of a region. But some drawbacks still exist, such as the transformity uncertainty of emergy (Campbell and Brown, 2012), only a static analysis of EF (Moffatt, 2000), and so on.

In principle, these six methods mainly differ in purposes, scopes, and data requirements, but all sharing the system approach in nature. None of them is perfect, nor can any single method solve all

Table 4
Comparison of six main methods in the field of natural resource accounting.

Methods	Initiated year /Initiator /Country	Definition	Metric	Standardization	Advantages	Disadvantages
Mathematic modeling	/	In this paper, mathematic method is a joint name that contains many mathematic methods, especially market value method, surrogate market method, and simulation etc.	/	/	·It is a traditional and popular approach to accounting monetary value of natural resources. (Woodward and Wui, 2001) ·It is easy to understand and acceptable by the public and governments.	·Monetary value may not represent the true value of natural resources completely. (Liu et al., 2016) ·The inevitable estimation increases the uncertainty of the results. (Woodward and Wui, 2001)
Emergy	1980s /Odum /USA	"*The available energy of one kind of previously used up directly and indirectly to make a service or product.*" (Odum, 1996)	solar emjoule	None, but most researchers follow Odum's methodology.	·Its evaluation is based on natural contribution. (Dong et al., 2016) ·It builds an interaction between ecosystem and economic system. (Campbell and Brown, 2012)	·It has uncertainty due to the data source and the availability of transformity for different resources. (Campbell and Brown, 2012; Dong et al., 2016)
Exergy	1870s /Gibbs /USA (systematical exploration from 1960)	"*The maximum amount of work which can be produced by a system or a flow of matter or energy as it comes to equilibrium with a reference environment.*" (Dincer, 2002)	joule	None, but it is based on the Second Law of Thermodynamics.	·It is an effective method to analyze energy efficiency and design more efficient energy system. (Dewulf et al., 2008) ·It offers a way to evaluate resource depletion and environmental destruction. (Dewulf et al., 2008)	·It needs to choose a reference state which may be some complex. (Rosen, 2002) ·The results of exergy analysis are not easy to interpret, understand and utilize. (Rosen, 2002)
EF	1990s /Wackernagel and Rees /Mexico;Canada	The biologically productive land and water that participants consume to produce resources and absorb generated wastes. (Wackernagel and Rees, 1997)	hectare	Standards defined by Global Footprint Network.	·It is easy to select data, calculate results and be understood by policy makers. (Dong et al., 2016) ·It could reflect the gap between social activities and ecological carrying capacity. (Wackernagel et al., 1999)	·It ignores some natural function and pollutants. (Wackernagel et al., 1999) ·It is a static method that can not reflect the dynamic change of the social system. (Moffatt, 2000) ·Transforming factor is very controversial. (Dong et al., 2016)
LCA	1960s /It was conceived by the Coca-Cola Co. In the USA.	"*Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.*" (ISO, 2006)	/	ISO 14040 ISO 14044	·The analysis process is quantitative, detailed and accurate. (Dong et al., 2016) ·It could avoid problem-shifting between different life-cycle phases or regions. (Rebitzer et al., 2004)	·It needs lots of detailed data and takes long time and high cost. (Dong et al., 2016) ·Some hypotheses and parameters may be subjective so that influent results. (Rebitzer et al., 2004)
MFA	1960s /Some developed countries used MFA to analyze city metabolism.	"*A systematic assessment of flows and stocks of materials within a system defined in space and time.*" (Brunner and Rechberger, 2004)	mass	None explicitly, but there are some handbooks for practitioners.	·It quantitatively evaluates the relationship between ecosystem and human society in a region. (Fischer-Kowalski et al., 2011) ·It could reveal the sources of environmental pressure to help policy making. (Fischer-Kowalski et al., 2011)	·It is hard to propose the system sustainable threshold. (Hendriks et al., 2000) ·It needs further concerns on hidden flow's coefficient, system internal analysis and data acquisition. (Hendriks et al., 2000)

the problems, leading to the combination need with other methods. In order to solve those issues, it will be rational to improve original methods like hybrid methods by combining two or three approaches (Nakajima and Ortega, 2016; Wang et al., 2015). This is confirmed by methods analysis shown in Fig. 10. For instance, the combinations of exergy, emergy and MFA with LCA have become more popular since all of them cover the entire cycle (mining, production, manufacturing, use, waste handling) of a certain substance within a given geographical boundary and time frame, which makes it suitable for studies involving resource scarcity and recycling from old scrap.

5. Conclusions

Natural resource accounting is critical to promote sustainable natural resources management. However, due to a lack of appropriate accounting methods, their true values have been biased, leading to rapid depletion and corresponding emissions. Also, no peer reviewed publication has completed a holistic review on summarizing the recent progress and point out future research directions. Under such a circumstance, this paper adopts the bibliometric analysis and the SNA methods to analyze the academic features of English language publications on natural resources accounting indexed by Scopus during 1995–2014. Results show that scientific attentions on this area have gradually increased due to the increasing concerns on natural resources. Journal of Environmental Management is the most productive journal, while Environmental Science and Technology is the most influential journal in terms of IF and *h*-index.

At the global scale, USA is the leading country with the most publications, international cooperation and highest academic influence. Both the most productive institution (University of California) and the most prominent author (Dr. Bakshi, B.R.) with high *h*-index are also from the USA. Following USA, China is the second most productive country and the only developing country that has 3 institutions listed in the top 10 most productive institutions. Meanwhile, the most productive author (Dr. Chen) is also from China. This is mainly due to the fact that China is playing a role of the world manufacturer and has a soaring demand on natural resources both at home and abroad. However, China's academic influence in this field is not that strong due to a lack of international collaboration and appropriate English presentation.

According to keywords analysis, water and energy are major investigated natural resources because of the large consumption demand, followed by land, forest, waste and urban ecosystem. Mathematic modeling, emergy, exergy, EF, LCA and MFA are mainstream research methods in this field. Especially, mathematic modeling is the most applied method although more recent studies have shifted from such an anthropocentric valuation to eco-centric valuation (emergy, exergy, EF, LCA and MFA). However, no single method can deal with such a complicated issue, therefore, integration of different methods is necessary so that more holistic and accurate accounting results on natural resources can be obtained for scientific decision-making.

In general, the purpose of this study is to provide a complete review on current progress and hot issues related with natural resources accounting. These findings can provide valuable insights to those researchers engaging in this field so that more research outcomes can be generated to guide sustainable natural resources utilization.

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