Renewable and Sustainable Energy Reviews 66 (2016) 95–104

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Characteristics and trends of research on waste-to-energy incineration: A bibliometric analysis, 1999–2015

Yuan Wang [a,b], Nan Lai [a], Jian Zuo [c,d], Guanyi Chen [a,b,*], Huibin Du [d]

[a] *School of Environmental Science and Engineering, Tianjin University, Tianjin, China*
[b] *China–Australia Centre for Sustainable Urban Development, Tianjin University, Tianjin, China*
[c] *School of Architecture & Built Environment,Entrepreneurship, Commercialisation and Innovation Centre (ECIC), The University of Adelaide, SA 5005, Australia*
[d] *College of Management and Economics, Tianjin University, Tianjin 300072, China*

A R T I C L E I N F O

Article history:
Received 6 February 2015
Received in revised form
21 March 2016
Accepted 1 July 2016
Available online 3 August 2016

Keywords:
Bibliometrics
Incineration
Statistical analysis
Co-words analysis
Waste-to-energy

A B S T R A C T

This study aims to provide an up-to-date contemporary bibliometric view of the waste-to-energy incineration literature and a correlative analysis of this field. Based on the bibliometric method, a statistical analysis was undertaken on papers published from 1999 to 2015 in Science Citation Index (SCI) and the Social Science Citation Index (SSCI). There were 4348 publications in the field of waste-to-energy incineration. The number of publications per year has increased steadily since 2009. China produced 15.71% of all pertinent articles followed by Japan with 11.37% and USA with 7.97%. China has played a key role in the collaboration network of 30 most productive countries and regions. In addition, the cooperation within the European countries was notable. However, China ranked first in all aspects except h-index. This means China's impact (number of citations) in this field could be further strengthened though its quantity (number of publications) was the highest. Five clusters were identified from keywords networks, i.e. Central Cluster node ("combustion"), Cluster(I) (central nodes were "fly ash"," heavy metal(s)" and "bottom ash"), Cluster(II) (central nodes were dioxin-related substances), Clusters(III) (central nodes focused on waste management), and Cluster(IV) "chemistry methods". These findings are useful for the future endeavor of waste-to-energy incineration academic research.

Contents

* Corresponding author at: School of Environmental Science and Engineering, Tianjin University, Tianjin, China.
E-mail address: Gychen_tju@163.com (G. Chen).

http://dx.doi.org/10.1016/j.rser.2016.07.006
1364-0321/

1. Introduction

Renewable energy has attracted a growing attention due to global warming and rapid depletion of natural resources [1,2]. It is well recognized that municipal solid waste (MSW) is a source of renewable energy due to its composition, e.g. wood or food as biomass materials [3,4]. As one of most popular approaches, waste-to-energy incineration helps to reduce the amount of waste sent to the landfill [5,6]. Waste-to-energy incineration can not only deal with the rapid growing amount of MSW arguably due to the expansion of the population but also satisfy the demand for energy by means of heat and electricity [7,8]. This indeed forms part of renewable energy production strategies [9,10].

Last decades have witnessed the rapid advancement of waste-to-energy incineration technologies from simple open pit burning in the 1950s to waste-to-energy plants with energy recovery as current practices which is highly efficient [11].

Major concerns to waste incineration plants include the air pollutants such as dioxins and heavy metals [3]. Indeed, there were no new WTE facilities in the USA since 1996 for a decade due to environmental and political pressure [3]. However, recently waste-to-energy incineration is receiving a growing attention in many countries due to the promotion of renewable energy developments and pressure on efficient land use. In Europe, the EU waste framework directive (2008/98/EC) emphasizes energy recovery from waste [5]. Waste incinerators play a critical role for the energy supply in several northern European countries [11]. The waste-to-energy incineration was used to treat more than 30% MSW in Germany. In Asia, in the Chinese government put forward "The 12th Five-Year Plan (2011–2015)", which specified that electricity generated from the waste incineration technologies will grow by 10%, reaching a proportion of 30% of the total energy mix in 5 years [12]. In Japan, approximately 80% of MSW is incinerated, where energy recovery has been included in a certain proportion of waste incineration plants [13]. In South Korea, the amount of energy generated from mixed wastes (incineration) contributed to more than 23% of the renewable energy production [4].

With the advancement of waste incineration and emissions control technologies, the related body of literature has grown substantially. Therefore, it is necessary to assess the development and growth of research related to the waste-to-energy incineration, especially during the past decade.

Bibliometrics provides a useful tool which quantitatively analyzes the development and growth of any specific research field [14–16]. Mathematical and statistical methods can be employed to examine various characteristics of publications such as the distributed architecture and variation patterns, which in turn reflect the status quo of the underlying science and technology [17]. Bibliometrics technique has been adopted in various energy-related fields such as alternative energy research [14], solar energy [18], and energy efficiency [19], however not on the waste-to-energy incineration. The objective of this study is to present a comprehensive analysis of publications related to waste-to-energy incineration by means of bibliometric method. As Municipal solid waste (MSW) is regarded as an important source of renewable energy, these results not only provide a better understanding of global hotspots in the specific research related to the waste-to-energy incineration, but may also provide useful information for the broader research area of renewable energy.

2. Methods

Multiple methods were employed in order to analyze the trends and characteristics of researches related to waste-to-energy incineration. These methods are: bibliometric, social network analysis, and h-index.

2.1. Bibliometric analysis

Bibliometric method is a combination of quantitative and qualitative of analysis which involves three typical models: Bradford literature dispersion law, Lotka's law, Zipf's Law [20–22]. 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 [23]. 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 one of most commonly adopted method to measure the progress in a specific scientific field [15]. The research objects can be all kinds of literatures themselves and the characteristics they reveal such as topics, authors, publication dates references, contents and so on.

Biblimetrics provides a useful tool to map the literature around a research field. It includes quantitative and visual processes to identify patterns and dynamics in scientific publications [24]. Bibliometric analysis has been guided by the objective of revealing global trends in certain areas of research [25]. The aspects of body of literature by Bibliometric method include both quantitative information (e.g. annual outputs, mainstream journals, leading countries and institutions) and qualitative data (e.g. hotspots and future research methods directions) [26].

2.2. Social network analysis (SNA)

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 [27,28]. Social network analysis is designed to model the dynamics between focus and relationships which has been employed in bibliometric related studies. SNA has been employed to highlight the relationships between various nodes in the networks. In the context of bibliometrics analysis, these nodes present countries, institutions, authors and keywords related to a specific research field. Data visualization plays a crucial role in network research. A variety of software are available to achieve the data visualization. Pajek and Gephi are two of powerful visualization tools for SNA. In this study, the academic collaboration among different countries and institutes were analyzed by using the Pajek software, and the clustering analysis of keywords were analyzed by using the Gephi software.

2.2.1. Co-word analysis

Co-word is one of the content analysis methods, which is originated from the late 1970s. As it is easy to operate, Co-word has been used to search management information systems, analyze the research trends [18], discover research hotpots [23] and identify the evolution of research topics [29]. Similar to co-citation and co-author analysis, co-word aims to identify Co-word and co-absence of keywords [30]. Based on co-word analysis method, there are mainly three steps for the clustering analysis (Bibexcel be used) [31]: (1) extract keywords or themes are retrieved from existing literature where keywords with high frequency are identified. Top 30 countries and institutes were selected for analysis in this paper. As there was no cooperation between some institutes, only 25 countries and institutes were further analyzed. Keywords were selected with a frequency greater than 3; (2) co-words matrix is established by counting the frequency that each pair of keywords occur in the same paper. This matrix serves as a critical input to the social network visualization software.

2.2.2. Clusters analysis

Clustering analysis was employed to examine the comprehensive relationship between keywords. Clusters are also called communities, groups or modules in SNA. It was designed to measure the structure of networks. Cluster(or community) structure detection is crucial to reveal the underlying structure of complex networks [32]. In general, nodes in the same cluster play similar roles in the network [33].

Modular functions of Gephi software was used in this study to detect these clusters. The first important part in the Gephi software is the Layout module, where Force Atlas2 algorithms were used to re-position the nodes in the graph. This algorithm can be used in typical networks of Gephi environment. It spatializes a

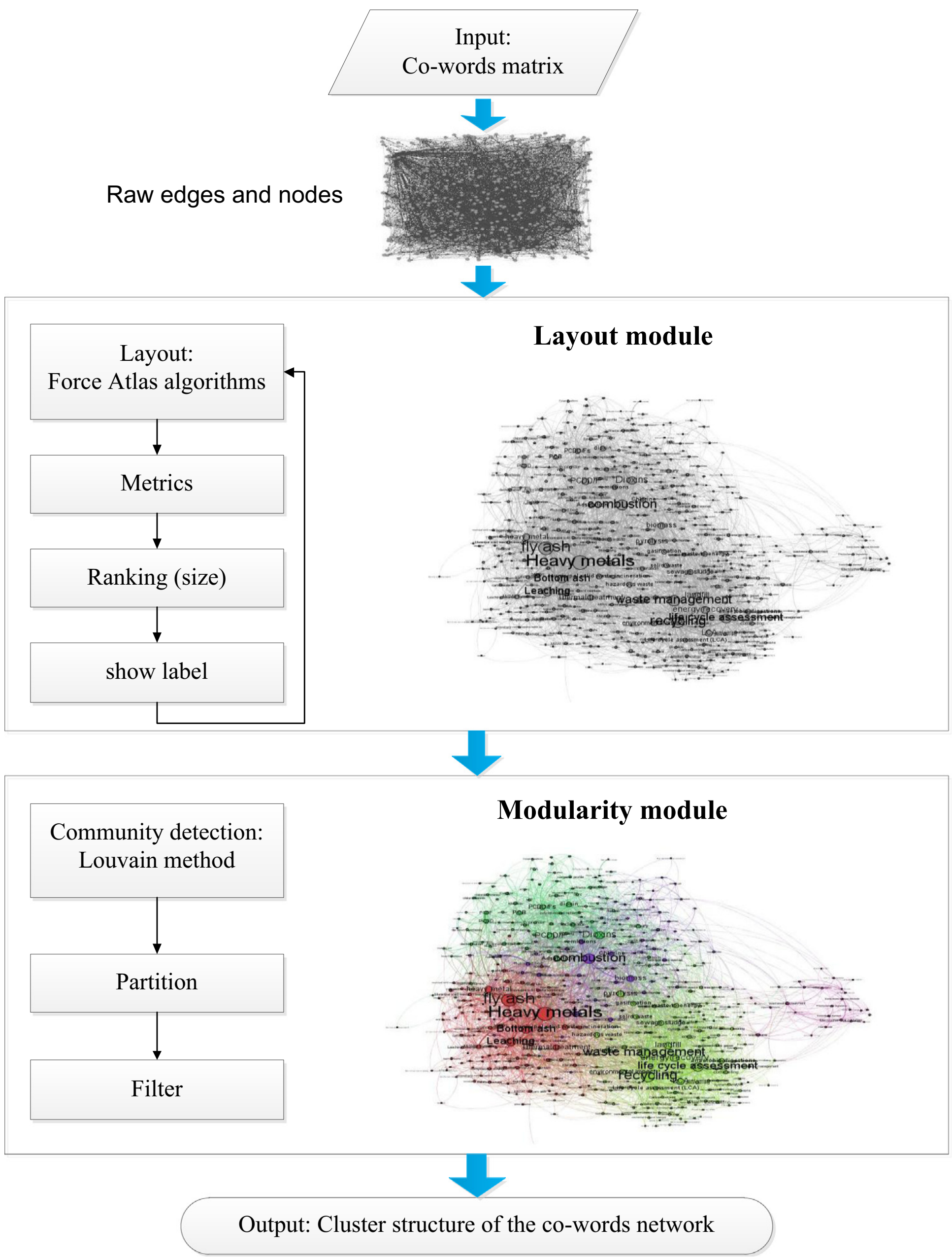

Fig. 1. Flow chart, step-by-step methodology (Source: http://gephi.org/). Note: Metrics: in this process, the average path length for the network was calculated. It computes the path length for all possible pairs of nodes and give information about how nodes are close from each other; Filter: Filters can be created to remove leaves, i.e. nodes with a single edge (Source: http://gephi.org/).

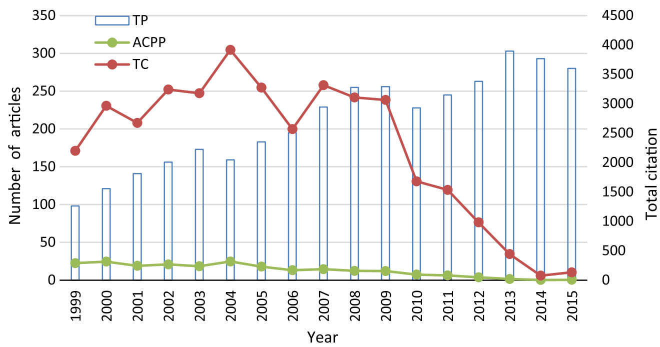

Fig. 2. TP, TC, and ACPP from 1999 to 2015. Note: TP-total number of publications, TC-total number of citations, ACPP-average citation per year.

network by means of simulating the associated physical system. As a result, the association of a node with its 'home' clusters is identified [33].

The second important part is the Modularity module. A "Modularity Class" value is computed by means of the community detection algorithm for each node via the Louvain method. As a kind of state-of-the-art technique, Louvain method (LM) provides a useful tool to examine large scale weighted networks [34]. Consequently, the partition module can be used to colorize clusters.

The whole procedure is showed as Fig. 1.

2.3. The impact factor and H-index

For countries, institutions and author of the publications, two measures of influence are employed in our analysis: the impact factor (IF) and the h-index. The quality and article diffusion during the period of study is analyzed through the Impact Factor. Each article has been assigned the impact factor of the journal in the year of publication in which it was published. This is the way in which the average IF value of publications from each center/country for a specific time period is calculated [35].

The h-index was first proposed by Hirsch [38] to measure the productivity and impact of published works of not only individual scholars, but also research organizations, countries, and journals collectively [36]. H-index is defined 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 [36]. In H-index, measures for quantity (i.e number of publications) and impact (i.e. number of citations) are integrated into a single indicator [37,38]. In this study, the h-indexes of research countries and institutes were calculated.

3. Results and discussions

The steps to obtain article information related to waste-to-energy incineration are described as follows:

– Step 1: keywords related to waste-to-energy incineration (i.e. seed keywords) were screened.
– Step 2: seed keywords were used to search the databases of Science Citation Index (SCI), the Science Citation Index Expanded (SCIE) and the Social Science Citation Index (SSCI). These databases cover a wide range of research fields and have been widely used in bibliometrics related studies as they offer more consistent and standardized records than others such as Scopus [39]. SCI and SCIE (Expanded SCI) mainly cover the natural science and engineering technology. SSCI covers anthropology, law, economics, history, geography, psychology and so on. Indeed, web of science is the most popular indexed database in bibliometrics related studies [40,41]. These keywords are: "incineration waste" or "incineration municipal solid waste" or "incineration waste-to-energy".
– Step 3: all literatures were located and stored in a dedicated folder.

A total of 4348 documents were retrieved from databases that were published from 1999 to 2015 These documents were analyzed according to their types, publication outputs, general patterns, citations, countries and institutions of publication, and keywords distribution, etc.

3.1. The general patterns

Of 4348 documents related to waste-to-energy incineration retrieved from SCI and SSCI databases over the last16 years, journal articles accounted for 82.29% (3578 records). Other types of documents include proceedings, reviews, meeting abstracts, letters, book chapters, etc. Therefore, only the type of article was considered in this study. As shown in Fig. 2, the total number of publications (TP) increased continually, in spite of some fluctuations throughout the period of time. By contrast, the total number of citations (TC) dropped significantly since 2004. Similarly, the annual average citation per year (ACPP) experienced a sharp decrease in last decade, from the highest (24.63 times) in 2004 to the lowest (0.26 times) in 2014.

3.2. The distribution of subject categories

These 3572 journal articles related to waste-to-energy incineration covered 164 subject categories in SCI and SSCI databases. The top 5 subjects in terms of the total number and annual number of published articles are shown in Fig. 3. Articles covering Environment Sciences and Engineering, Environmental experienced explosive growth since 2006. In contrary, the number of articles in other areas only gained a slow growth. Thus, the main research areas of waste-to-energy incineration are Environment Sciences and Engineering.

3.3. The performance of journals

A total of 656 journals have published articles related to waste-to-energy incineration from 1999 to 2015. Table 1 listed top 5 journals in terms of the number of publications related to waste-to-energy incineration. Waste management, Chemosphere, Journal of hazardous materials, Waste Management & Research, and Environmental Science & Technology were the five most popular journals in this field. Waste Management took the first place with

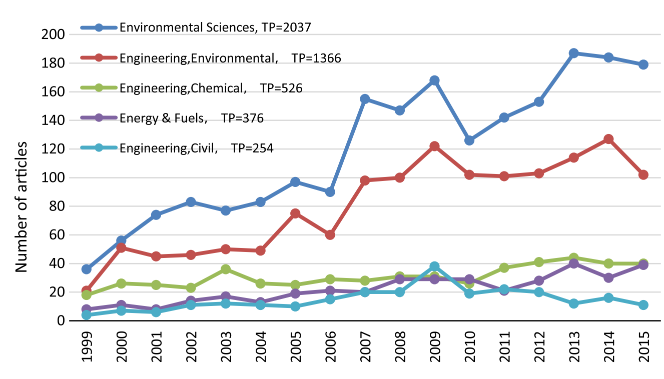

Fig. 3. Number of articles addressing different subjects, 1999–2015.

Table 1
Top 5 productive journals in the publication of waste-to-energy incineration area during 1999–2015.

Journal name	TP	%	IF2015[a]
Waste Management	391	10.93	3.22
Chemosphere	213	5.95	3.34
Journal of Hazardous Materials	199	5.56	4.53
Waste Management & Research	175	4.89	1.30
Environmental Science & Technology	136	3.90	5.33

TP: the number of total publications; %, ratio of one journal's publications to total number of publications; IF: impact factor.

[a] Data source: http://www.medsci.cn/sci/.

391 articles (10.93%), much higher than Chemosphere, the second placed journal with 213 articles (5.95%). Among these top five journals, the impact factor of the Environmental Science & Technology was the highest (IF=5.33), though it ranked lower in terms of the total number of published articles.

3.4. An analysis of countries

3.4.1. The performance of different countries

From 1999 to 2015, 90 countries have contributed to publishing articles on waste-to-energy incineration. This is contrast to a total of 191 countries across the world. The initial analysis showed that 25 of 3578 articles lacked the information of author's address. Of the remaining 3553 articles, only 18.01% involved international collaboration. Table 2 shows the top ten countries and regions with respect to a number of indices such as the number of total published articles, the percentage of publications involved international collaboration as well as the country's h-index.

In these ten most productive countries and regions, six countries were from Europe, three were Asian countries and one was from North America. China is the most productive country with 558 articles, followed by the Japan (404) and USA (283). Moreover, China is the most productive country with the largest number in all aspects (i.e. total number of publications, single-country publications, internationally collaborative publications, and the number of publications of first author's country), except h-index. China's h-index (29) was only ranked fifth, which indicated that its impact in this field could be further strengthened. Italy ranked the first in terms of h-index (40), indicating that it had a relatively higher level of influence in the field. It is worth noting that the ranking of single country publications was lower than that of internationally collaborative publications in most countries, except Japan, Italy, Spain and Taiwan. In particular, Taiwan ranked 4th in terms of single country publications whilst ranked 17th in terms of the number of internationally collaborative publications. International cooperation in the field of waste-to-energy incineration could be further strengthened.

Table 2
Top 10 productive countries in the publication of waste-to-energy incineration area during 1999–2015.

Country	TP	TP R (%)	SP R (%)	CP R (%)	FP R (%)	H-index
China	558	1(15.71)	1(14.32)	1(22.03)	1(14.55)	5(29)
Japan	404	2(11.37)	2(10.4)	3(15.78)	2(9.79)	2(33)
USA	283	3(7.97)	5(5.49)	2(19.22)	4(5.66)	2(33)
Italy	283	3(7.97)	3(7.48)	7(10.16)	3(7.09)	1(40)
Germany	227	5(6.39)	6(4.87)	4(13.28)	6(4.9)	4(31)
Sweden	209	6(5.88)	7(4.7)	5(11.25)	7(4.87)	9(28)
Taiwan	207	7(5.83)	4(6.25)	17(3.91)	5(5.43)	10(23)
UK	195	8(5.49)	8(4.29)	6(10.94)	8(4.31)	7(26)
France	173	9(4.87)	9(3.88)	8(9.38)	9(3.94)	7(26)
Spain	158	10(4.45)	10(3.78)	11(7.5)	10(3.72)	5(29)

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.

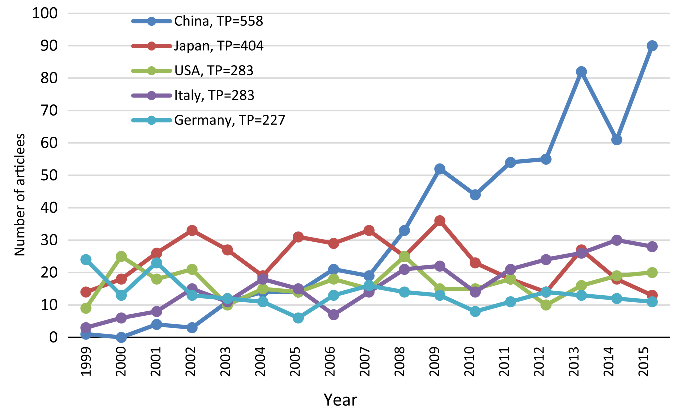

Fig. 4. Annual number of publications by the 5 most productive countries, 1999–2015.

Fig. 4 shows the top 5 most productive countries with respect to the time-trend analysis during 1999–2015. It demonstrated that all the countries experienced an increasing trend in the annual number of publications. It is worth noting that the number of papers published by Chinese scholars experienced sharp increase since 2009 compared to other countries. This may attribute to the growing attention of the government and public on waste-to-energy incineration in China.

3.4.2. Cooperation analysis of countries

Based on the social network analysis, the coauthoring relationship amongst the 30 countries in the field of waste-to-energy incineration was described by means of the cooperation network diagram (see Fig. 5). Pajek software was employed to draw the diagram on the basis of co-word matrices generated from Bibexcel. It could intuitively reflect the relationships among high frequency keywords. The ultimate graph with nodes 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 [23].

As shown in Fig. 5, China has played a key role in the collaboration network of 30 most productive countries and regions. China had developed partnerships with several other countries, particularly with Japan, USA, Netherlands and UK. The cooperation between China and Japan is particularly notable, rising to the first place in terms of intensity. In Japan, approximately 80% of MSW is incinerated [13], and the incinerated MSW increased 7 times in China during the last decade (National Bureau of Statistics of China, 2013). Both Japan and China has a high population density and experiences difficulties to locate suitable sites for landfill. This has demanded more researches on the waste-to-energy incineration. In addition, the cooperation within European countries were also notable, as energy recovery and GHG emissions reduction from waste incineration draw more attention in these countries.

3.5. The analysis of institutions

More than half of 1893 articles (53.28%) involved multi-institutional collaboration. Table 3 showed ten most productive institutes in the research field of waste-to-energy incineration during 1999–2015.

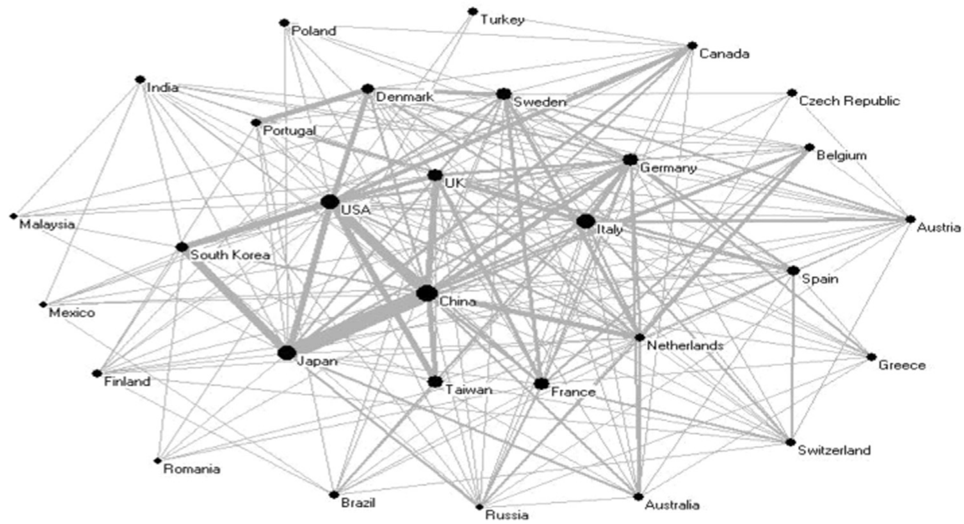

Fig. 5. Collaboration relationships between the 30 most productive countries.

Table 3
Top 10 productive institutions in the publication of waste-to-energy incineration area during 1999–2015.

Institute	TP	TP R (%)	h-index
Technical University of Denmark, Denmark	113	1(3.18)	1(22)
Chinese Academy of Sciences, China	95	2(2.67)	7(13)
Zhejiang University, China	82	3(2.30)	4(14)
National Institute for Environmental Studies, Japan	58	4(1.63)	2(16)
Tongji University, China	49	5(1.37)	8(12)
The University of Sheffield, UK	47	5(1.32)	2(16)
Kyoto University, Japan	45	7(1.26)	4(14)
Tsinghua University, China	44	8(1.23)	10(9)
National Chung Hsing University, Taiwan	41	9(1.15)	4(14)
National Cheng Kung University, Taiwan	36	10(1.01)	9(11)

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
Subordinates of the top 3 institutes during 1999–2015.

Institute	Subordinate	TP
Technical University of Denmark, Denmark	Department of Environment and Engineering	78
	Department of Civil Engineering	23
	Institute of Environment and Resources	15
Chinese Academy of Sciences, China	Research Center for Eco-Environment Sciences	45
	Dalian Institute of Chemical Physics	14
	Institute of Applied Ecology	8
Zhejiang University, China	State Key Laboratory of Clean Energy Utilization	50
	Institute for Thermal Power Engineering	48
	College of Environment and Resource Sciences	6

Among the top 10 institutes, six came from China, two from Japan, one from the UK and Denmark respectively. This reiterated the predominance of China in the research field of waste-to-energy incineration. The Technical University of Denmark had the highest contribution with 113 articles in the total volume of publications, followed by the Chinese Academy of Sciences (95) and Zhejiang University in China (82). In terms of the h-index, Technical University of Denmark also ranked the first, followed by National Institute for National Institute for Environmental Studies, Japan and The University of Sheffield, UK. These institutes had a relatively higher level of influence in the research field of waste-to-energy incineration.

The analysis was extended to departments of the top 3 institutes (i.e. Technical University of Denmark, Denmark; Chinese Academy of Sciences, China and Zhejiang University, China, see Table 4). As the most productive institute on waste-to-energy incineration, the Technical University of Denmark's most productive subordinate is the Department of Environment and Engineering (78). Chinese Academy of Sciences is the second ranked productive institute, and its most productive subordinate is Research Center for Eco-Environment Sciences (45). The third ranked productive institute is the Zhejiang University, China with two main subordinates, i.e. State Key Laboratory of Clean Energy Utilization (50) and Institute for Thermal Power Engineering (48). These figures provide useful indication of research performance of institutions at the department level.

The cooperative relationships among the top 25 productive institutes during 1999–2015 were shown in Fig. 6. It can be observed that the closest collaborative relationship exists between the Kyoto University of Japan and National Institute for Environmental Studies of Japan; between National Chung Hsing University of Taiwan and National University of Kaohsiung of Taiwan; and between Zhejiang University of China and Chinese Academy Science of China. As shown in Fig. 5, the cooperation between institutions was mainly within the same country. This suggested opportunities to strengthen the international cooperation in order to further enhance productivity of these top institutions.

3.6. An analysis of keywords

Author keywords describe main topics of articles and are usually used to analyze the emerging trends in research [42,43]. A total of 6700 author keywords were supplied by 3578 articles, of which 5132(76.60%) of which h were used only once, and 733 (10.94%) keywords were used twice. A large number of keywords appeared only once, which indicates a variety of research priorities. 295 (4.4%) keywords appeared more than 3 times, indicating that they were related to main research streams of waste-to-energy incineration.

Cluster analysis was undertaken in order to identify main research streams by using Gephi, an interactive visualization and

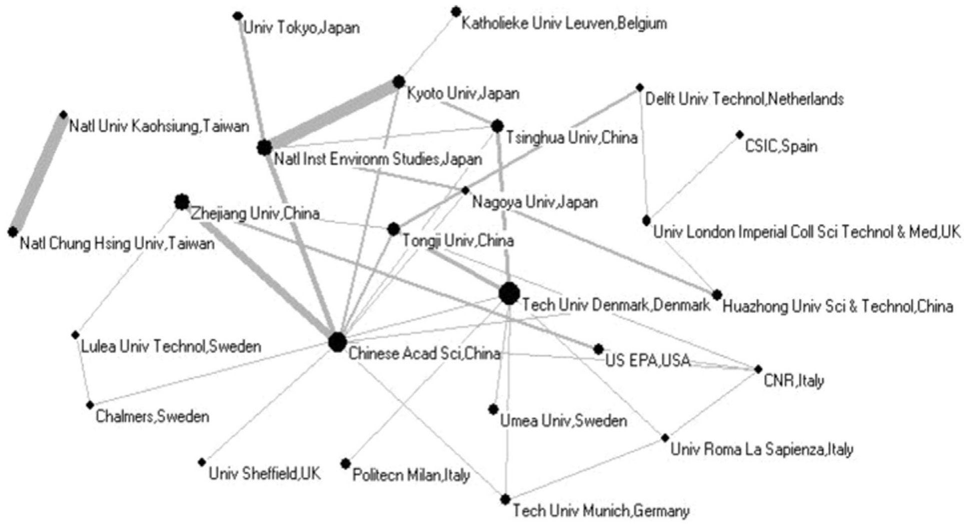

Fig. 6. Cooperation network of the top 25 productive institutes.

exploration platform for all kinds of networks. The bibliometric networks were visualized and clustered. The data displayed according to the Force Atlas2 Layout. As shown in Fig. 7, these clusters varied in size and partially overlapped.

As shown in Fig. 7, the Central Cluster is related to thermal treatment technologies, including combustion, gasification, biomass and pyrolysis. The "Combustion" is the node with the biggest size in the Central Cluster. Combustion is also called incineration, which is one of most popular thermal treatment methods applied to deal with different types of waste [44]. The Central Cluster was surrounded by Cluster (I), (II) and (III).

Central nodes of the Cluster(I) were "fly ash", "heavy metal(s)" and "bottom ash"; Central nodes of the Cluster (II) were dioxin-related substances, such as "dioxin(s)", "PCDD/Fs", "PCDD" and "PCDD/F". The two Clusters were strongly interconnected with pollutants, which is the most important area in waste-to-energy incineration research. Central nodes of the Cluster (III) focused on management areas, such as "life cycle assessment (LCA)", "waste management", and "recycling". This is another core area in waste-to-energy incineration related researches.

Cluster (IV) is somewhat separate from other clusters with the smaller size nodes. It represented some chemistry methods, for leachate treatment, such as "Electrochemical Oxidation", "Anodic Oxidation", "anaerobic digestion" and "Electrochemical Degradation". Although leachate is one of most critical pollutants, significantly less attention has been placed on leachate treatment, which demands future research.

The network analysis of keywords provided a useful indication of main topics within the waste-to-energy incineration research area. Temporal trends of main clusters (I), (II) and (III) were analyzed in order to obtain a deeper understanding of these topics.

3.6.1. Clusters (I) and (II) – pollutants

About 50% keywords were about pollutions derived from the incineration process. This suggested that environmental issues associated with waste-to-energy incineration have drawn most attention from scholars. Under this topic, 1257 references were retrieved in the SCI and SSCI databases. The keyword of "ash" (TP=371) was the top pollutant, followed by "dioxin-related substances" (TP=357) and "Heavy metal" (TP=262). This indicated atmospheric pollutants from waste incineration were mostly concerned by scholars in this field.

Keyword "ash" included "fly ash" and "bottom ash". Most of ash related researches focused on "fly ash" (80%). Although a certain amount of heating and power energy is generated during the MSW incineration process, the MSW-incinerated fly ash is a hazardous waste which poses a serious threat to surroundings. Combustion emissions were one of major contributors of air pollutants such as the fine particle (PM2.5) [45]. Moreover, the fly ash may contain a number of contaminants, such as heavy metals, polycyclic aromatic hydrocarbons (PAHs), and polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) [46]. A growing number of researches focused on the combined pollution from fly ash produced by the waste incineration. As a result, the keyword "ash" was much more popular than other keywords (see Fig. 8).

Keywords of "dioxin-related substances (i.e. PCDD, PCDD/Fs, PCDD/F, dioxin et al.)" are also worth noting (Fig. 8). Due to its highly hazardous substances, PCDD/Fs are one of critical impeding factors for the adoption of MSW incineration. Since 1970s, a large number of studies have been conducted on dioxin-related substances. In spite of notable achievements, the mechanisms of PCDD/Fs formation and the influence of critical factors remained debatable. As shown in Fig. 7, the researches on dioxin-related substances increased steadily from 1999 to 2015. Nevertheless, it remains unclear the appropriate ratio of homogeneous to heterogeneous PCDD/Fs for waste incinerators [47], which demands future research.

During the incineration process, heavy metals could remain in final residues and in gaseous emissions [48]. This may lead to severe environmental pollution. Therefore, the thermodynamics behavior of heavy metal should be examined with the assistance of kinetic information [49]. Other critical pollutants include Fe, Cu, Cr, Al, and Cd [50]. Due to rapid development of air pollution control measures for municipal solid waste incineration, more attention has been paid to solid residues [51]. As a result, the keywords "heavy metal" has increased continuously since 1999 (Fig. 7).

3.6.2. Clusters (III) – management

Under this topic, 603 references were retrieved from the SCI and SSCI databases. In this field, "life cycle assessment (LCA)" was the largest area, followed by "waste management", "recycling" and "Energy recovery". It's worth noting the frequency of "LCA" has increased significantly recently (Fig. 8). This showed that the life cycle approach has been recognized as the most appropriate approach to study waste-to-energy incineration related issues. During last decades, life cycle assessment (LCA) has been used extensively to evaluate the environmental benefits and drawbacks of

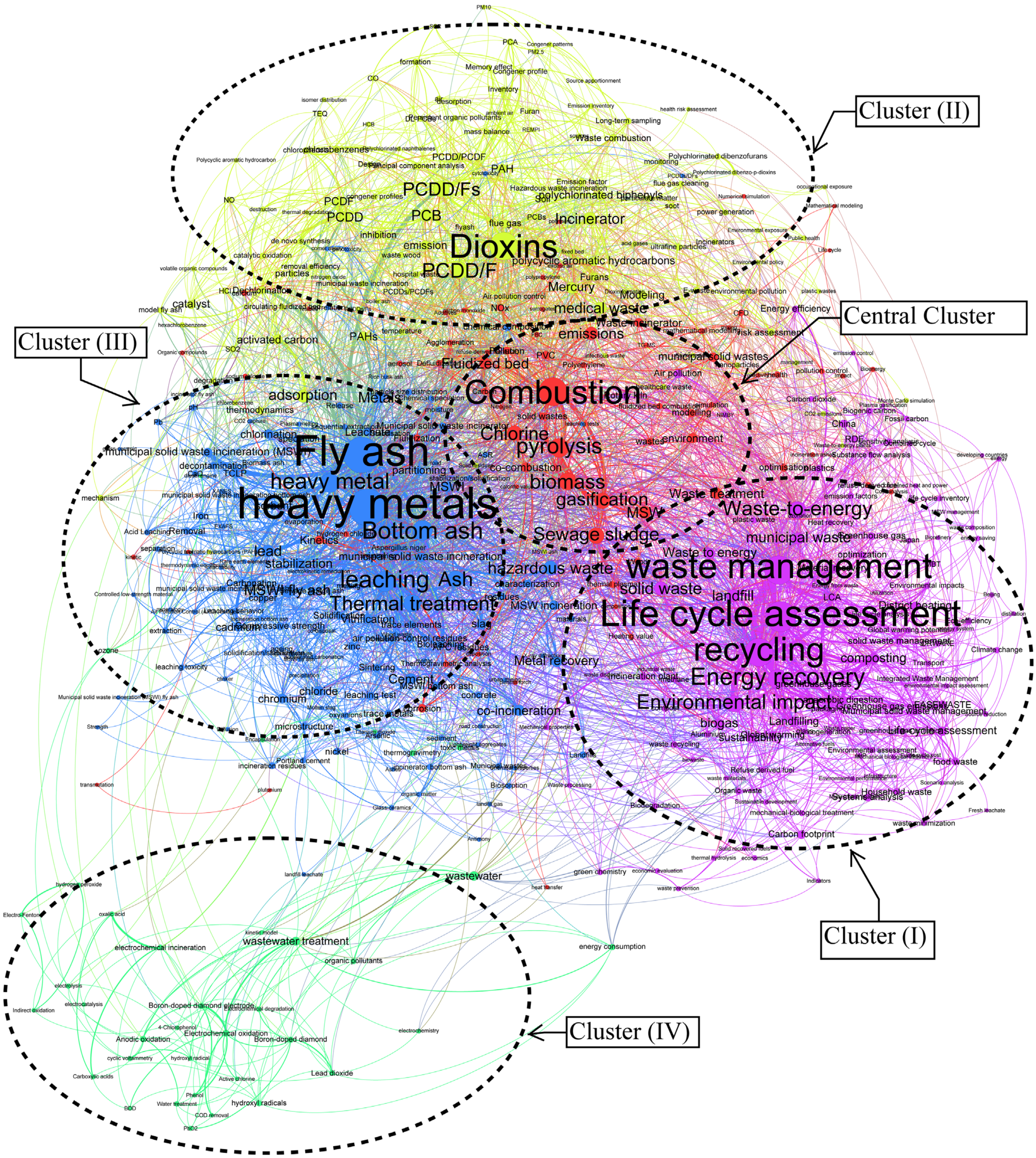

Fig. 7. The co-words network (478 nodes, 3888 links). Nodes represent papers and links represent shared reference between papers. Large nodes have more shared references. The length of connection between the two nodes represents the total co-words frequency of the two Approximate location of clusters is indicated with: the Central Cluster was combustion; Cluster(I) central nodes were "fly ash", "heavy metal(s)" and "bottom ash"; Clusters(II) central nodes were dioxin-related substances; Clusters (III) central nodes focused on waste management area; Clusters(IV) represent some chemistry method of leachate treatment. Colors indicate the listed clustered topics.

various waste management approaches, including waste-to-energy incineration technologies. However, a detailed and systematic review of assessment choices and inventory data specifically related to waste-to-energy incineration technologies are needed [52].

"Energy recovery" is also one of top keywords for the research field of waste-to-energy incineration. The heat value of MSW is generally low in most regions. This could present as a critical barrier for the promotion of waste incineration as a kind of renewable energy development. This is arguably due to lack of

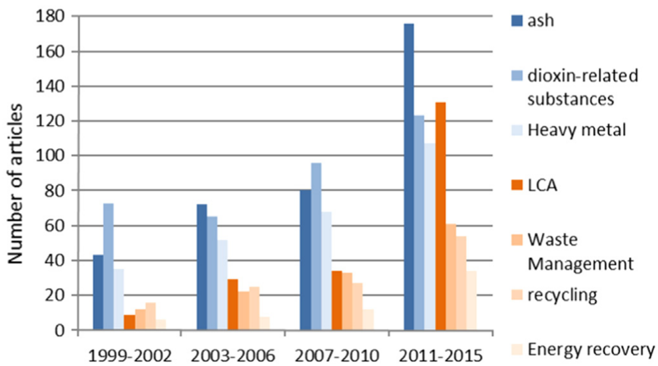

Fig. 8. The growth trend of main keywords.

garbage classification in those regions. Garbage classification can not only improve the efficiency of waste incineration, but also helps to achieve "recycling" of resources [12].

3.7. Citation analysis

Table 5 showed the top 5 most highly cited articles (TI), journal's title (SO), author's name and country (RP-CC), year (PY) and total citations (TC). Most of authors are from European countries. The most highly cited article was entitled "Management of municipal solid waste incineration residues". The authors of this article were from a working group where member are scholars from Austria, Italy, Denmark, Germany. This paper was published in Waste Management with 133 total citations. It specially focused on assessing the environmental impacts of residues derived from waste incineration, as well as treatment methods available to mitigate such impacts.

The second and third highly cited articles focused on utilizing fly ash. One article introduced an innovative vitrification technique to stabilize and recycle toxic incinerator fly ash; the other article systematically reviewed nine possible applications of fly ash, followed by proposing a framework for the selection of the best technology and final products.

The last two highly cited articles mainly focused on management areas. All these authors came from KTH (Royal Institute of Technology) in Sweden. The article entitled "Life cycle assessment of energy from solid waste – part 1: general methodology and results" showed a detailed description of the LCA evaluation process, including the provision of waste management hierarchy system in order to achieve the conversion of waste to renewable fuel, and to evaluate the quality management methods. The other article entitled "Municipal solid waste management from a systems perspective" placed the focus on the advantages and disadvantages of different waste treatment methods (e.g. incineration, materials recycling and biological treatment) compared with landfill.

4. Conclusions

Bibliometric technique offers a quantitative perspective which provides a better understanding of the characteristics associated with body of literature related to waste-to-energy incineration research. This study provides a suite of indicators that can be combined to provide a useful picture for the development of waste-to-energy incineration research, such as TP, TC, ACPP, IF and so on. Moreover, the visualized SNA method adopted in this study provides an innovative tool which could be used in future bibliometric studies to analyze hot topic in renewable energy research fields.

Using bibliometric methods, characteristics of the waste-to-energy incineration literature from 1999 to 2015 based on the SCI and SSCI databases were examined. This study revealed that there was an increasingly level of research activities on waste-to-energy incineration in terms of the number of publications. However, the total number of citations (TC) dropped significantly since 2004. China is an important contributor to the waste-to-energy incineration literature with the most publications (558), followed by the Japan (404) and USA (283). However, China's impact in this field could be further strengthened as its h-index ranked only 5th. The analysis of institutions showed that the Technical University of Denmark was the most significant contributor with 113 papers and its most productive subordinate was the Department of Environment and Engineering.

This study also found that five core journals, namely Waste Management, Chemosphere, Journal of Hazardous Materials, Waste Management & Research, and Environmental Science & Technology, contribute to about 32% of the total journal literature on waste-to-energy incineration. "Environment Sciences" is the hottest subject with the most waste-to-energy incineration publications.

The cooperation analysis of countries showed that only small proportion of waste-to-energy incineration related studies involved international collaboration. Therefore, efforts are required to encourage more collaboration amongst researchers from different countries to tackle this field. International collaboration is also helpful for capacity building and may assist the technology transfer to deal with various issues associated with waste-to-energy incineration. This could be very useful for developing countries that are generally short of capital and technical expertize to deal with sustainability related issues.

The analysis of keywords showed there were two hot topics in waste-to-energy incineration research area. The first is pollutants research, such as "fly ash", "heavy metals", "dioxin-related substances", the second is management research, such as "life cycle assessment (LCA)", "energy recovery" and "recycling". The temporal trends showed that LCA on waste-to-energy incineration increased significantly recently, however, relatively little methodological consistency exists between individual LCA studies in waste-to-energy research area. The keyword "ash" was much more popular than other keywords from 1999 to 2015. Most of ash related researches ate "fly ash", which may contain a number of

Table 5
Top 5 most highly cited articles in waste-to-energy incineration area during 1999–2015.

Title	Author	SO	RP-CC	TC	PY
Management of municipal solid waste incineration residues	Polettini, A[53]	Waste Management	Italy	133	2003
Vitrification of fly ash from municipal solid waste incinerator	Park, YJ[54]	Journal Of Hazardous Materials	South Korea	128	2002
Possible applications for municipal solid waste fly ash	Ferreira, C[55]	Journal Of Hazardous Materials	Denmark	127	2003
Life cycle assessment of energy from solid waste - part 1: general methodology and results	Finnveden, G[56]	Journal Of Cleaner Production	Sweden	118	2005
Municipal solid waste management from a systems perspective	Eriksson, O[57]	Journal Of Cleaner Production	Sweden	118	2005

SO: the publication journal; RP-CC: country of correspondence author; PY: publish year; TC: total citation contaminants, such as heavy metals and dioxin.

China is the most productive country in the research field of waste-to-energy incineration, because China has a high population density and experiences difficulties in locating suitable landfill sites, which has demanded to develop waste-to-energy incineration plants. Waste-to-energy is considered as playing an important role in not only the energy mix to fulfill fast growing energy demands but also combating climate change. Environmental issues such as pollutant emission attract most attention in the existing body of knowledge, which clearly indicates a growing public concern on positional environmental issues associated with waste-to-energy incineration process. Therefore, it could be an effective policy to facilitate the development of waste-to-energy incineration plants by mandating the requirements of reducing environmental impacts associated with the waste incineration. The government could implement the Maximum Available Control Technology (MACT) regulations to reduce the emissions of heavy metal and dioxins in fly ash. In addition to that, the research policy on the waste-to-energy area could possibly focus on the technology for Air Cleaning System.

Acknowledgments

This research has been supported by the Project of National Science and Technology Pillar Program of China (2014BAC26B05–01) and the Natural Science Foundation of China (Grant nos. 41571522 and 71273185).

References

[1] Yuan X, Wang X, Zuo J. Renewable energy in buildings in China—a review. Renew Sustain Energy Rev 2013;24:1–8.
[2] Zuo J, Zhao ZY. Green building research–current status and future agenda: a review. Renew Sustain Energy Rev 2014;30:271–81.
[3] Psomopoulos CS, Bourka A, Themelis NJ. Waste-to-energy: a review of the status and benefits in USA. Waste Manag 2009;29:1718–24.
[4] Ryu CK. Potential of municipal solid waste for renewable energy production and reduction of greenhouse gas emissions in South Korea. J Air Waste Manag 2010;60:176–83.
[5] Monni S. From landfilling to waste incineration: Implications on GHG emissions of different actors. Int J Greenh Gas Control 2012;8:82–9.
[6] Jeswani HK, Smith RW, Azapagic A. Energy from waste: carbon footprint of incineration and landfill biogas in the UK. Int J LCA 2013;18(1):218–29.
[7] Pavlas M, Touš M, Klimek P, Bébar L. Waste incineration with production of clean and reliable energy. Clean Technol Environ 2011;13(4):595–605.
[8] de Souza SN, Horttanainen M, Antonelli J, Klaus O, Lindino CA, Nogueira CE. Technical potential of electricity production from municipal solid waste disposed in the biggest cities in Brazil: Landfill gas, biogas and thermal treatment. Waste Manag Res 2014;32(10):1015–23.
[9] Tsai WT, Chou YH. An overview of renewable energy utilization from municipal solid waste (MSW) incineration in Taiwan. Renew Sustain Energy Rev 2006;10(5):491–502.
[10] Yuan H, Lu W, Jianli Hao J. The evolution of construction waste sorting on-site. Renew Sustain Energy Rev 2013;20:483–90.
[11] Brinck K, Poulsen TG, Skov H. Energy and greenhouse gas balances for a solid waste incineration plant: a case study. Waste Manag Res 2011;29:13–9.
[12] Zhao XG, Jiang GW, Li A, Li Y. Technology, cost, a performance of waste-to-energy incineration industry in China. Renew Sustain Energy Rev 2016;55:115–30.
[13] Tabata T. Waste-to-energy incineration plants as greenhouse gas reducers: a case study of seven Japanese metropolises. Waste Manage Res 2013;31:1110–7.
[14] Mao GZ, Liu X, Du H, Zuo J, Wang LY. Way forward for alternative energy research: A bibliometric analysis during 1994–2013. Renew Sustain Energy Rev 2015;48:276–86.
[15] Van Raan AFJ. For your citations only? Hot topics in bibliometric analysis Measurement 2005;3(1):50–62.
[16] Mao G, Zou H, Chen G, Du H, Zuo J. Past, current and future of biomass energy research: A bibliometric analysis. Renew Sustain Energy Rev 2015;52:1823–33.
[17] Dong J, Chi Y, Zou D, Fu C, Huang Q, Ni M. Energy–environment–economy assessment of waste management systems from a life cycle perspective: model development and case study. Appl Energy 2014;114:400–8.
[18] Du H, Li N, Brown MA, Peng Y, Shuai Y. A bibliographic analysis of recent solar energy literatures: The expansion and evolution of a research field. Renew Energy 2014;66:696–706.
[19] Du H, Wei L, Brown MA, Wang Y, Shi Z. A bibliometric analysis of recent energy efficiency literatures: an expanding and shifting focus. Energy Efficiency 2013;6:177–90.
[20] Fairthorne RA. Empirical hyperbolic distributions (Bradford-Zipf-Mandelbrot) for bibliometric description and prediction. J Doc 1969;25(4):319–43.
[21] Tsay MY, Jou SJ, Ma SS. A bibliometric study of semiconductor literature, 1978–1997. Scientometrics 2000;49(3):491–509.
[22] Yang ZK, Lin DM, Xu MZ. The re-applicability explore of Lotka's law in patent documents. Collnet J Scientometr Inform Manag 2014;8(1):183–91.
[23] Du H, Li BL, Brown MA, Mao G, Rameezdeen R, Chen H. Expanding and shifting trends in carbon market research: a quantitative bibliometric study. J Clean Prod 2015;103:104–11.
[24] Pritchar A. Statistical bibliography or bibliometrics. J Doc 1969;25(4):348 –&.
[25] Tarkowski SM. Environmental health research in Europe – bibliometric analysis. Eur J Public Health 2007;17:14–8.
[26] Fu HZ, Wang MH, Ho YS. Mapping of drinking water research: A bibliometric analysis of research output during 1992–2011. SCI Total Environ 2013;443:757–65.
[27] Serrat O. Social Network Analysis Washington, DC: Asian Development Bank; 2009 (URL: <http://digitalcommons.ilr.cornell.edu/intl/206/>.
[28] Prell C. Social network analysis: history, theory and methodology. Sage Publication Ltd; 2011.
[29] Li J, Wang MH, Ho YS. Trends in research on global climate change: a science citation index expanded-based analysis. Global Planet Change 2011;77:13–20.
[30] Ronda-Pupo GA, Guerras-Martin LA. Dynamics of the evolution of the strategy concept 1962–2008: a co-word analysis. Strateg Manag J 2012;33(2):162–88.
[31] Zhang W, Zhang Q, Yu B, Zhao L. Knowledge map of creativity research based on keywords network and co-word analysis, 1992–2011. Qual Quant 2015;49(3):1023–38.
[32] Jacomy M, Venturini T, Heymann S, Bastian S. ForceAtlas2, a continuous graph layout algorithm for handy network visualization designed for the Gephi software. PLoS One 2014;9(6):e98679.
[33] Kauffman J, Kittas A, Bennett L, Tsoka S. DyCoNet: a Gephi plugin for community detection in dynamic complex networks. PLoS One 2014;9(7):e101357.
[34] P. De Meo E. Ferrara G. Fiumara A. Provetti. Generalized Louvain method for community detection in large networks. In: Proceedings of the international conference on intelligent systems design and applications, 2011, p. 88–93.
[35] Canas-Guerrero I, Mazarron FR, Calleja-Perucho C, Pou-Merina A. Bibliometric analysis in the international context of the "Construction & Building Technology" category from the Web of Science database. Constr Build Mater 2014;53:13–25.
[36] Hirsch JE. An index to quantify an individual's scientific research output. Proc Natl Acad Sci USA 2005;102(46):16569–72.
[37] Harzing AW, Van Der Wal R. A google scholar h-index for journals: an alternative metric to measure journal impact in economics and business. J Am Soc Inf Sci Tech 2009;60(1):41–6.
[38] Baldock C, Ma R, Orton CG. The h-index is the best measure of a scientist's research productivity. Med Phys 2009;36(4):1043–5.
[39] Bettencourt LMA, Kaur J. Evolution and structure of sustainability science. Proc Natl Acad Sci USA 2011;108(49):19540–5.
[40] Rojas-Sola JI, de San-Antonio-Gomez C. Bibliometric analysis of Spanish scientific publications in the subject Construction & Building Technology in Web of Science Database (1997–2008). Mater Construc 2010;60(300):143–9.
[41] Lopez-Illescas C, de Moya-Anegon F, Moed HF. The actual citation impact of European oncological research. Eur J Cancer 2008;44(2):228–36.
[42] Yu AT, Poon CS, Wong A, Yip R, Jaillon L. Impact of construction waste disposal charging scheme on work practices at construction sites in Hong Kong. Waste Manag 2013;33(1):138–46.
[43] Zhang GF, Xie SD, Ho YS. A bibliometric analysis of world volatile organic compounds research trends. Scientometrics 2010;83(2):477–92.
[44] Lombardi L, Carnevale E, Corti A. A review of technologies and performances of thermal treatment systems for energy recovery from waste. Waste Manag 2015;37:26–44.
[45] Ragazzi M, Tirler W, Angelucci G, Zardi D, Rada EC. Management of atmospheric pollutants from waste incineration processes: the case of Bozen. Waste Manage Res 2013;31(3):235–40.
[46] Zhang L, Su XW, Zhang ZX, Liu S. Characterization of fly ash from a circulating fluidized bed incinerator of municipal solid waste. Environ Sci Pollut R 2014;21:12767–79.
[47] Zhou H, Meng A, Long Y, Li Q, Zhang Y. A review of dioxin-related substances during municipal solid waste incineration. Waste Manag 2015;36:106–18.
[48] Brunner PH, Monch H. The flux of metals through municipal solid waste incinerators. Waste Manag Res 1986;4:105–19.
[49] Abanades S, Flamant G, Gauthier D, Tomasa S, Huangb L. Development of an inverse method to identify the kinetics of heavy metal release during waste incineration in fluidized bed. J Hazard Mater 2005;124:19–26.
[50] Feng SL, Wang XM, Wei GJ, Peng PG, Yang Y, Cao ZH. Leachates of municipal solid waste incineration bottom ash from Macao: heavy metal concentrations and genotoxicity. Chemosphere 2007;67:1133–7.
[51] Van der Sloot HA, Kosson DS. Hjelmar, characteristics, treatment and utilization of residues from municipal waste incineration. Waste Manag 2001;21:753–65.
[52] Astrup TF, Tonini DR, Boldrin A. Life cycle assessment of thermal waste-to-energy technologies: review and recommendations. Waste Manag 2015;37:104–15.
[53] Sabbas T, Polettini A, Pomi R, Astrup T, Hjelmar O, Mostbauer P, Cappai G, Magel G, Salhofer S, Speiser C, Heuss-Assbichler S, Klein R, Lechner P. Management of municipal solid waste incineration residues. Waste Manag 2003;23(1):61–88.
[54] Park YJ, Heo J. Vitrification of fly ash from municipal solid waste incinerator. J Hazard Mater 2002;91(1–3):83–93.
[55] Ferreira C, Ribeiro A, Ottosen L. Possible applications for municipal solid waste fly ash. J Hazard Mater 2003;96(2–3):201–16.
[56] Finnveden G, Johansson J, Lind P, Moberg A. Life cycle assessment of energy from solid waste – part 1: general methodology and results. J Clean Prod 2005;13(3):213–29.
[57] Eriksson O, Reich MC, Frostell B, Bjorklund A, Assefa G, Sundqvist JO, Granath J, Baky A, Thyselius L. Municipal solid waste management from a systems perspective. J Clean Prod 2005;13:241–52.