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A bibliometric analysis of solid waste research during the period 1993–2008

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ABSTRACT

This study is a bibliometric analysis of solid waste research to evaluate the current trends, using the literature in the Science Citation Index (SCI) database from 1993 to 2008. Analyzed aspects included document type, language, and publication output as well as distribution of journals, subject category, countries, institutes, title-words, author keywords, and 'Keywords Plus'. An evaluating indicator, h-index, was applied to characterize the solid waste publications. The trend of publication outputs during 1993–2008 coincided with a power and an exponential model. Based on the exponential model during 2001–2008, the number of articles on solid waste in 2013 is predicted to be twice that in 2008. The most common subject category is environmental science and the most productive journal is *Waste Management*. The USA with most publications and China with the highest growth rate were compared. Finally, author keywords, words in title, and 'Keywords Plus' were analyzed to provide research emphasis. The results showed that mainstream research was centered on the following methods: recycling, landfilling, composting and waste-to-energy. Heavy metals, fly ash and sewage sludge were considered recent research hotspots.

1. Introduction

Numerous studies have been carried out on the various aspects of solid waste research, such as landfilling, composting and incineration. Meanwhile, these studies were published in diverse journals of many subject categories and were written by researchers from a number of countries all over the world. However, no systematic analysis of the scientific research on solid waste management has been carried out to date.

Bibliometric methods have been used to measure scientific progress in many disciplines of science and engineering, and are a common research instrument for systematic analysis (Van Raan, 2005). Furthermore, the Institute for Scientific Information (ISI) Web of Science databases, particularly the Science Citation Index (SCI), are used to analyse research performance from an international perspective (Moed, 2002). Since Narin et al. (1976) first proposed the concept of "evaluative bibliometrics," many scientists have tried to evaluate the research trend in the publication outputs of countries, research institutes, journals, and subject category (Garcia-Rio et al., 2001; Zhou et al., 2007), the citation analysis (Cole, 1989), and the peak year citation per publication (Chuang et al., 2007; Li and Ho, 2008). In recent years, more information, closer to the research itself, such as the distribution of different words in the paper title (Xie et al., 2008; Li et al., 2009), author keywords (Xie et al., 2008; Mao et al., 2010), 'Keywords Plus' (Xie et al., 2008; Li et al., 2009), and words in abstracts (Zhang et al., 2009) have been presented in the study of research trends. The term 'Keywords Plus' refers to searches that include the traditional keywords, plus additional search terms to maximize retrieval of important, relevant articles (Garfield, 1990a,b).

The h-index has been used to characterize both the quantity and significance of a scientist's research publications, as first proposed by Hirsch (2005). H-index is defined by the h of N_p papers having at least h citations each and the other (N_p-h) papers have $\leqslant$h citations each (Hirsch, 2005). Clive et al. (2009) argues that this new measure has become an accepted indicator for evaluation of the research productivity of scientists. However, its limitations should be acknowledged. It does not take into account differences between journals and disciplines in citation behavior. Issues with its mathematical properties have also been raised (Waltman and van Eck, 2009).

A common method for assessing a journal's relative influence is the Impact Factor (IF) (Chiu and Ho, 2007), which is the average number of times articles from the journal published in the past 2 years have been cited in the Journal Citation Reports (JCR) year and calculated by dividing the number of citations in the JCR year by the total number of articles published in the two previous years. Although widely reported, the use of IF must be done with care. Some concerns with the IF include:

(1) It only considers citations in the 2 years after publication.
(2) Two journals could have the same IF even though one has many uncited articles and a few with a high number of citations.

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(3) There is no method to adjust based on the varying number of citations typical for certain journals or disciplines.
(4) No distinction is made between the types of articles: review articles, discussion articles, research articles.
(5) Citations can be counted for types of publications (e.g., editorials) that are not counted in the denominator as 'citable' articles.

This aim of this study was to systematically evaluate not only the conventional research aspects covering document type, language, countries of publication, institutes, journals, and subject category, but also the innovative research aspects, covering words in the paper title, author keywords, and 'Keywords Plus' analysis, with h-index as an assessment indicator, to obtain an overview of solid waste research during the period from 1993 to 2008.

2. Methods

One common method of bibliometric research is to trace publications using the SCI of the Institute for Scientific Information (ISI). Documents used in this study were based on the database of the SCI obtained by subscription from the ISI, Web of Science, Philadelphia, USA. JCR deliver quantifiable statistical information based on citation data. The 2008 edition of the JCR published by ISI lists 173 subject categories including 6620 journals in the SCI. Since 1991, abstract information has been included in the SCI. The topic search can trace the related information in the title, abstract, and keywords at one time. "Solid waste*" was used as a search phrase to search topics in SCI for the period from 1993 to 2008. This search term included "solid waste," and "solid wastes," (6678) "solid wasteforms (1)," and "solid waster (1)."

Aspects referring to document type, language, output, subject category, journal, country, institute, source title, keyword, and h-index were all analyzed by Microsoft Excel 2007. The contribution of different countries and institutes were estimated by the location of the affiliation of at least one author of the published papers. Articles that originated from Hong Kong were not included under the China heading for analysis. Articles that originated from England, Scotland, Northern Ireland, and Wales were grouped under the UK heading. "Internationally collaborative publication" was designated to those articles that were coauthored by researchers from more than one country, where "independent type" was assigned if the researchers' addresses were from the same country. The term "single institute publication" was assigned if the researchers' addresses were from the same institute. The term "inter-institutionally collaborative publication" was assigned if the authors were from different institutes. The reported IF of each journal was obtained from the 2008 JCR.

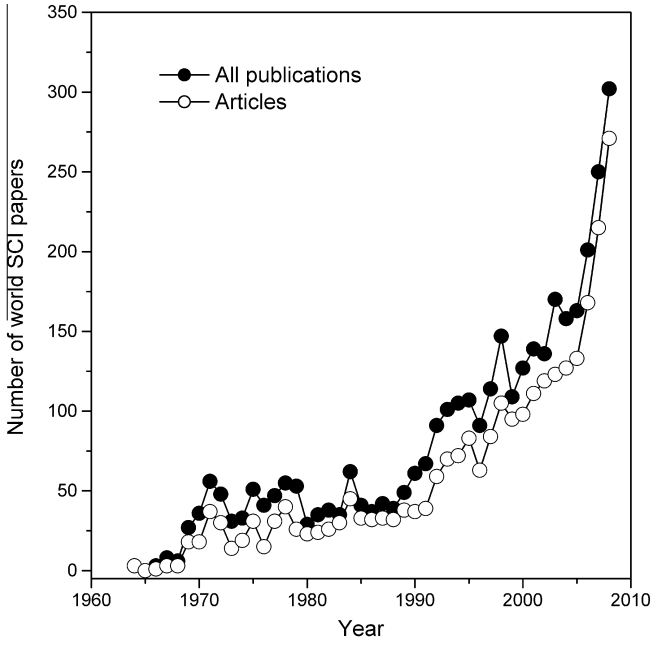

Fig. 1. Number of SCI publications referring to "solid waste*" only in the title.

3. Results and discussion

3.1. Document type and language of publication

The 6680 publications related to solid waste identified by the ISI between 1993 and 2008 included 13 document types. Articles

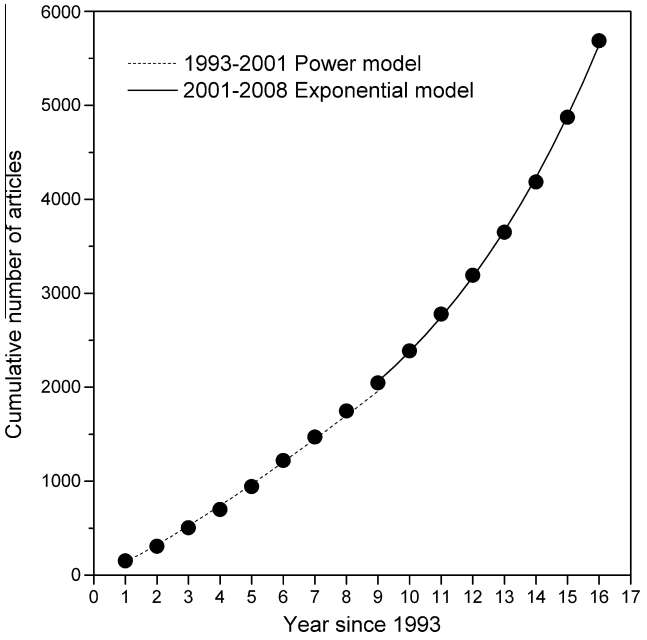

Fig. 2. The relationship between cumulative number of publications and published year.

Table 1
Characteristics by year of publication outputs from 1993 to 2008.

Year	TP	AU	AU/TP	PG	PG/TP	NR	NR/TP
1993	152	426	2.8	1679	11	2146	14
1994	154	415	2.7	1565	10	2462	16
1995	198	574	2.9	1789	9.0	2835	14
1996	195	542	2.8	2107	11	4038	21
1997	243	705	2.9	2821	12	5680	23
1998	277	875	3.2	2756	9.9	6142	22
1999	250	844	3.4	2614	10	5543	22
2000	277	904	3.3	2697	9.7	6185	22
2001	300	976	3.3	3123	10	6948	23
2002	340	1172	3.4	3273	9.6	7873	23
2003	391	1380	3.5	4041	10	9847	25
2004	414	1484	3.6	4001	9.7	10,449	25
2005	458	1662	3.6	4475	9.8	12,463	27
2006	536	1949	3.6	5235	9.8	15,568	29
2007	688	2602	3.8	6592	9.6	19,831	29
2008	815	3081	3.8	7422	9.1	23,832	29
Total	5688	19,591		56,190		141,842	
Average			3.4		9.9		25

TP: number of publications; AU: number of authors; PG: page count; NR: cited reference count; and AU/P, PG/P and NR/P: average number of authors, pages, references per articles.

were the dominant document type comprising 81% of the total production. The remaining publications were proceedings papers (819), reviews (260), editorial materials (79), meeting abstracts (61), news items (30), notes (14), letters (13), corrections (6), book reviews (4), addition corrections (3), reprints (2), and discussions (1). On average, there were 22 articles per review and 72 articles per editorial material. Just one discussion means that the scientists conducted their research independently. As articles (5688) were the dominant type of document, these were analyzed in the following study.

For language analysis, 5512 articles (97%) were published in English, followed by Japanese (43), German (30), Spanish (29), Portuguese (24), French (15), Polish (12), Chinese (12), Czech (4), Russian (2), and only one article each in Rumanian, Italian, Turkish, and Korean, respectively. Obviously, English was by far the dominant language in the journals listed in SCI.

3.2. Characteristics of publication outputs

As there are no abstracts in the publications of the SCI before 1991, "solid waste*" was used as a search phrase in the title only to obtain a general long-term trend of solid waste research. The earliest research on solid waste was published in the 1960s. Fig. 1 shows that solid waste research fluctuated continually before 1990 with an upward trend. The amount of solid waste research started to increase significantly after 1991 and rocketed during the period from 2005 to 2008. The safe disposal of solid waste has become a primary environmental problem worldwide.

During the study period, the cumulative number of articles grew from 152 in 1993 to 5688 in 2008. A power model and an exponential model described the relationship between the annual cumulative number of articles and the year published for the two periods from 1993 to 2001 and 2001 to 2008, respectively (Fig. 2). A significant correlation between the number of articles and the year was observed with a high coefficient of determination (>0.997). Both the power and the exponential curve fitting indicated that there was a high growth rate for annual articles. The power and exponential fitting curves for solid waste research were found to be: $C = 141Y^{1.20}$ and $C = \exp(0.144Y + 6.34)$, respectively, where C is the cumulative number of articles and Y is the number of years since 1993. Based on the exponential model during 2001–2008, the number of articles in 2013 is predicted to be twice that in 2008.

Table 2
Top 20 most productive journals (1993–2008) with the number of papers, IF, h-index, ISI category of journals, and the position of the journal in its category.

Journal	TP (%)	Subject category (position)	IF (R)	h-Index (R)
Waste Management	394 (6.9)	Environmental engineering (7/38) Environmental sciences (44/163)	2.208 (8)	25 (2)
Waste Management & Research	347 (6.1)	Environmental engineering (19/38) Environmental sciences (133/163)	0.835 (16)	19 (6)
Journal of Hazardous Materials	241 (4.2)	Environmental engineering (5/38) Civil engineering (1/91) Environmental sciences (25/163)	2.975 (5)	22 (4)
Resources Conservation and Recycling	212 (3.7)	Environmental engineering (19/38) Environmental sciences (100/163)	1.133 (12)	17 (8)
Bioresource Technology	207 (3.6)	Agricultural engineering (1/9) Biotechnology & applied microbiology (17/144) Energy & fuels (2/67)	4.453 (2)	24 (3)
Chemosphere	185 (3.3)	Environmental sciences (23/163)	3.054 (4)	21 (5)
Environmental Science & Technology	172 (3.0)	Environmental engineering (2/38) Environmental sciences (7/163)	4.458 (1)	28 (1)
Journal of the Air & Waste Management Association	96 (1.7)	Environmental engineering (9/38) Environmental sciences (54/163) Meteorology & atmospheric sciences (19/52)	2.02 (10)	11 (14)
Journal of Environmental Engineering-ASCE	90 (1.6)	Environmental engineering (21/38) Civil engineering (26/91) Environmental Sciences (106/163)	1.085 (13)	16 (10)
Compost Science & Utilization	90 (1.6)	Ecology (101/124) Soil science (26/31)	0.638 (19)	15 (12)
Environmental Technology	85 (1.5)	Environmental sciences (143/163)	0.674 (18)	10 (16)
Science of the Total Environment	69 (1.2)	Environmental sciences (33/163)	2.579 (6)	15 (12)
Water Research	59 (1.0)	Environmental engineering (3/38) Environmental sciences (13/163) Water resources (1/60)	3.587 (3)	19 (6)
Journal of Environmental Management	54 (0.95)	Environmental sciences (66/163) Environmental studies	1.794 (11)	10 (16)
Fresenius Environmental Bulletin	53 (0.93)	Environmental sciences (154/163)	0.463 (20)	7 (18)
Fuel	53 (0.93)	Energy & fuels (11/67) Chemical engineering (7/116)	2.536 (7)	17 (8)
Journal of Geotechnical and Geoenvironmental Engineering	50 (0.88)	Geological engineering (11/25) Multidisciplinary geosciences (103/143)	0.849 (15)	12 (14)
Environmental Monitoring and Assessment	46 (0.81)	Environmental sciences (112/163)	1.035 (14)	6 (19)
Journal of Environmental Sciences-China	45 (0.79)	Environmental sciences (139/163)	0.72 (17)	4 (20)
Journal of Environmental Quality	45 (0.79)	Environmental sciences (49/163)	2.098 (9)	16 (10)

TP (%): total number of publications and percentage of total publication for a certain journal; IF: Impact Factor; and R: rank.

Characteristics of the annual production are illustrated in Table 1. The number of references cited per article increased more than twofold from 14 in 1993 to 29 in 2008, with a similar increase in the number of authors per article from 2.8 in 1993 to 3.8 in 2008. The average article length fluctuated slightly, with an overall average length of 9.9 pages. Of the 5688 articles, 232 (4.1%) articles did not include references, and the most common number of references per article was 20 which were found in 190 articles (3.3%). Of the 232 articles without references, 165 (75%) articles were published between 1993 and 1995.

Articles (5688) were analyzed, including 19 articles without author information. The most frequent number of authors was three accounting for 1470 articles (26%). Two to four authors accounted for 3893 articles (69%) and 491 articles (8.6%) had one author. The 5688 articles contained a total of 56,190 pages, excluding 19 articles without page information in the SCI. The maximum number of pages per article was 68 and the minimum number was one. Seven and eight pages (1467; 26%) were the most frequent number of pages.

3.3. Publication patterns: subject categories and journals

Articles (5688) were published in 860 journals in 112 subject categories in SCI. Table 2 lists the 20 most productive journals with both IF and h-index. The IF of a journal, cannot be adjusted for just the solid waste articles in a journal. *Waste Management* published the most articles, 394 (6.9%), followed by *Waste Management & Research* (347) and *Journal of Hazardous Materials* (241) which ranked 1st in the civil engineering category, based on the journal IF. Of the 20 most productive journals, *Bioresource Technology* ranked 1st in the agricultural engineering category and *Water Research* (207) ranked 1st in the water resources category. *Environmental Science & Technology* (172; 3%) was ranked 2nd in the environmental engineering category, with the highest h-index (28) and IF (4.458) among the journals on solid waste. The relationship between h-index, IF, and the rank order of the 20 most productive journals revealed similar trends. However, *Waste Management* which published the greatest number of articles had an h-index of 25, an IF of 2.208, and was ranked 2nd and 8th, respectively.

For subject category analysis, 5588 articles including 4 articles without subject category information were analyzed statistically. As illustrated in Fig. 3, based on the continuous increase in the number of articles per category, solid waste research has steadily increased especially at the beginning of the 21st century in many subject categories. The two most common categories were environmental sciences and environmental engineering, followed distantly by other categories. Of the 860 journals publishing the 5688 articles, 403 (47%) journals contained 1 article, 147 (17%) journals contained 2 articles, 64 (7.4%) journals contained 3 articles and 46 (5.3) journals contained 4 articles. Approximately 1758 (31%) articles were published in 7 core journals, and for comparison the trends in the 7 journals with the greatest number of articles are shown in Fig. 4. The number of articles in *Waste Management*, *Journal of Hazardous Materials*, and *Bioresource Technology* has increased significantly in recent years, while others increased but with a lower growth rate. In particular, *Waste Management* became the most productive journal for the first time in 2005, and has taken the lead in solid waste publishing in recent years and can hardly be exceeded by other study fields for years to come. The number of articles in *Bioresource Technology* was greater than that in *Journal of Hazardous Materials* for the first time in 2008, which indicated that more and more attention to the biotechnology field.

3.4. Publication performances: institutes and countries

Excluding 84 articles without any author address information on the ISI Web of Science, of the 5604 articles from 107 countries, 4719 (84%) were independent publications and 885 (16%) were international collaborative publications. Table 3 shows the top 20 most productive countries for total publications. The top 20 most productive countries included 95% of the total number of articles. The seven major industrialized countries (G7: Canada, France, Germany, Italy, Japan, the UK, and USA), ranked in the top 12 in Table 3, had 50% over the investigation period. The USA dominated, ranking first in both independent and collaborative publications, and

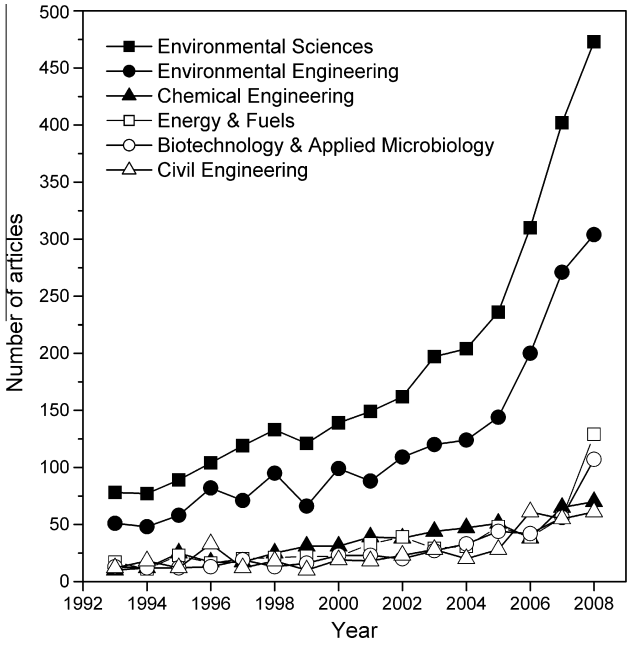

Fig. 3. The growth trends of the top 6 subject categories.

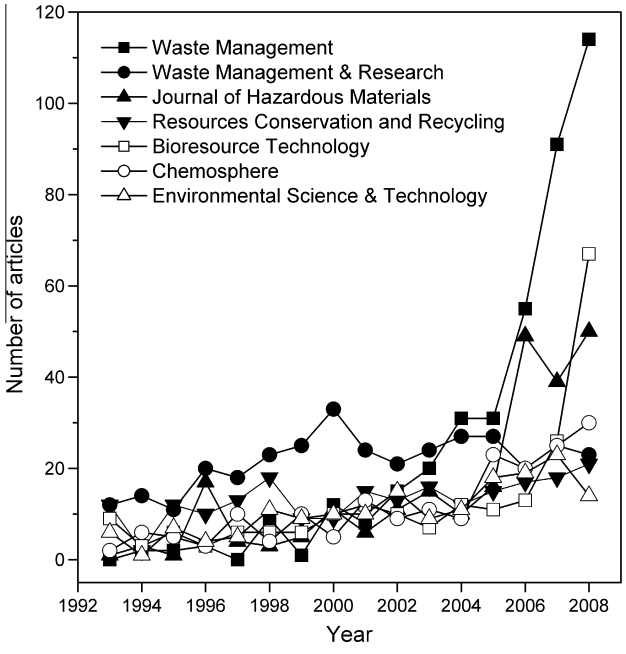

Fig. 4. The growth trends of the top 7 journals.

Table 3
Top 20 most productive countries of articles during 1993–2008.

Country	TP	TP (R) [%]	SP (R) [%]	CP (R) [%]	FA (R) [%]	RP (R) [%]	CP	CP (R) [%]	h-Index (R)
USA	1093	1 (20)	1 (18)	1 (28)	1 (17)	1 (17)	251	23 (13)	39 (1)
Spain	409	2 (7.3)	2 (6.4)	4 (12)	2 (6.6)	2 (6.4)	107	26 (12)	26 (2)
China	382	3 (6.8)	5 (5.3)	2 (15)	3 (5.9)	3 (5.9)	134	35 (6)	13 (18)
Japan	360	4 (6.4)	4 (6.0)	8 (8.7)	5 (5.6)	5 (5.8)	77	21 (15)	21 (6)
India	357	5 (6.4)	3 (6.4)	11 (6.4)	3 (5.9)	4 (5.9)	57	16 (17)	25 (3)
Canada	341	6 (6.1)	7 (4.9)	3 (13)	6 (5)	6 (5.1)	111	33 (10)	21 (6)
Italy	290	7 (5.2)	6 (4.9)	10 (6.7)	7 (4.6)	7 (4.6)	59	20 (16)	24 (4)
UK	287	8 (5.1)	9 (4.3)	6 (9.5)	8 (4.2)	8 (4.2)	84	29 (11)	21 (6)
Taiwan	259	9 (4.6)	8 (4.7)	15 (4.1)	9 (4.2)	8 (4.2)	36	14 (18)	20 (10)
France	225	10 (4.0)	11 (3.1)	7 (9.0)	11 (3.2)	11 (3.2)	80	36 (5)	21 (6)
Turkey	205	11 (3.7)	10 (3.8)	21 (2.9)	10 (3.5)	10 (3.6)	26	13 (19)	17 (13)
Germany	203	12 (3.6)	13 (2.3)	5 (11)	13 (2.6)	13 (2.6)	95	47 (1)	22 (5)
Sweden	182	13 (3.2)	12 (2.5)	9 (7.1)	12 (2.8)	12 (3.0)	63	35 (7)	18 (12)
South Korea	141	14 (2.5)	15 (2.0)	12 (5.2)	14 (2.2)	14 (2.2)	46	33 (9)	16 (15)
Brazil	122	15 (2.2)	16 (2.0)	19 (3.2)	16 (1.9)	16 (1.9)	28	23 (14)	9 (20)
Greece	113	16 (2.0)	14 (2.2)	32 (1.2)	15 (1.9)	15 (2.0)	11	10 (20)	15 (17)
Denmark	103	17 (1.8)	17 (1.2)	12 (5.2)	17 (1.4)	17 (1.5)	46	45 (2)	17 (13)
Netherlands	91	18 (1.6)	19 (1.1)	14 (4.3)	19 (1.2)	19 (1.1)	38	42 (4)	20 (10)
Australia	85	19 (1.5)	18 (1.2)	18 (3.3)	18 (1.3)	18 (1.3)	29	34 (8)	13 (18)
Belgium	74	20 (1.3)	23 (0.87)	16 (3.7)	22 (0.93)	22 (1.0)	33	45 (3)	16 (15)

TP: total publications; SP: independent publication; CP: international collaborative publication; FA: publication of the country of the first author; RP: publication of the country of corresponding author; %TP: share in publication; and %CP: the percentage of international collaborative publications in total publications.

had the highest h-index of 39. However, the USA was ranked 13th of the 20 countries on percentage of collaboration with outside authors, while Germany, ranked 12th in the number of publications, had the highest proportion of collaborative articles to total publications. Simultaneously, Germany was ranked 1st with 47% of international collaborative publications in its total publications. Based on intensifying academic exchanges in the solid waste study area, especially in recent years, collaboration is now frequent worldwide.

The USA had the highest h-index of 39 and eight countries had an h-index of 21–30. It is notable that China was ranked 3rd in the number of publications but only 18th in h-index and the Netherlands was ranked 18th in the number of publications but 10th in h-index. Fig. 5 shows the USA with the greatest number of articles. However, the USA did not have the highest growth rate and energy in recent years. The number of solid waste related articles from China was greater than that from the USA for the first time in 2008. China had the highest growth rate from 0 in 1993 to 107 in 2008, followed distantly by other countries.

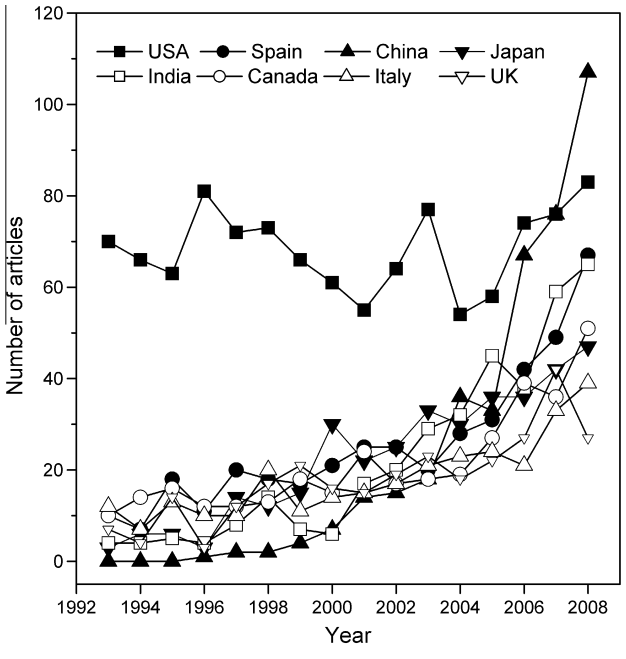

Fig. 5. The growth trends of the 8 most productive countries.

Of 5604 articles from 3513 institutes in 107 countries, 2473 (44%) were inter-institutionally collaborative publications, and 3131 (56%) were independent publications. The percentage of collaboration between institutes was much higher than that between countries (16%). Four institutes in the USA, three in China, two each in Spain, Taiwan, and Japan, and one each in Denmark, India, Canada, UK, Italy, Sweden, and Singapore were ranked in the top 20 most productive institutes as shown in Table 4. It is worth noting that the Spanish National Research Council, the Indian Institute of Technology and the Chinese Academy of Sciences ranked 1st, 4th, and 5th, respectively, are integrated research centers and are made up of many relatively independent institutes distributed throughout their country. The publications of these three institutes were pooled in one heading, and publications divided into branches would result in different rankings. With the exception of these three institutes, the most productive institute is the University of Florida (88; 1.6%) with a high h-index of 20, followed by the Technical University of Denmark (80; 1.4%). The National Taiwan University ranked 6th in the number of publications and 2nd in the number of inter-institutionally collaborative publications, but ranked only 19th and 21st in the number of articles from the institutes of the affiliation of first author and corresponding author, respectively. The University of Regina had the highest percentage (85%) of inter-institutionally collaborative publications of its total publications. Moreover, the h-index for Chinese Academy of Sciences, Tongji University, and Zhejiang University in China is 8, 7, and 7, respectively, which was accordant with country analysis.

3.5. Research emphasis: author keywords, words in title and 'Keywords Plus'

Statistical analysis of keywords and title-words can be used to identify directions in science (Garfield, 1990a,b), and has proved to be significant in monitoring the development of science and programs. Bibliometric analysis of author keywords has been carried out only in recent years (Chiu and Ho, 2007), whereas using author keywords to analyze trends in research is much more infrequent

Table 4
The 20 most productive institutes between 1993 and 2008.

Institute, country	TP	TP (R) [%]	SP (R) [%]	CP (R) [%]	FA (R) [%]	RP (R) [%]	CP (R) [%]	h-Index (R)
Spanish National Research Council, Spain	122	1 (2.2)	1 (2.0)	1 (2.4)	1 (1.7)	1 (2.2)	49 (15)	22 (1)
University of Florida, USA	88	2 (1.6)	2 (1.5)	5 (1.7)	2 (1.2)	2 (1.5)	48 (16)	20 (2)
Technical University of Denmark Denmark, Denmark	80	3 (1.4)	5 (0.93)	2 (2.1)	3 (1.1)	3 (1.5)	64 (8)	15 (4)
Indian Institutes of Technology, India	63	4 (1.1)	9 (0.73)	6 (1.6)	5 (0.86)	6 (1.1)	63 (9)	12 (6)
Chinese Academy of Sciences, China	59	5 (1.1)	6 (0.80)	7 (1.4)	4 (0.87)	4 (1.2)	58 (11)	8 (15)
National Taiwan University, Taiwan	59	5 (1.1)	28 (0.38)	3 (1.9)	19 (0.43)	21 (0.53)	80 (2)	8 (15)
National Cheng Kung University, Taiwan	58	7 (1.0)	3 (1.1)	17 (0.89)	5 (0.86)	5 (1.2)	38 (19)	15 (4)
University of Regina, Canada	54	8 (1.0)	56 (0.26)	4 (1.9)	10 (0.59)	10 (0.88)	85 (1)	10 (10)
Tongji University, China	51	9 (0.91)	6 (0.80)	8 (1.1)	7 (0.79)	7 (1.1)	51 (13)	7 (19)
University of Sheffield, UK	46	10 (0.82)	4 (1.1)	47 (0.53)	8 (0.70)	8 (1.1)	28 (20)	9 (13)
University of Rovira i Virgili, Spain	43	11 (0.77)	14 (0.57)	11 (1.0)	8 (0.70)	9 (0.90)	58 (11)	16 (3)
Zhejiang University, China	40	12 (0.71)	12 (0.64)	20 (0.81)	11 (0.54)	11 (0.75)	50 (14)	7 (19)
Nagoya University, Japan	35	13 (0.62)	48 (0.29)	8 (1.1)	13 (0.52)	12 (0.70)	74 (5)	8 (15)
University of Illinois, USA	35	13 (0.62)	19 (0.45)	19 (0.85)	17 (0.45)	28 (0.45)	60 (10)	12 (6)
University of Roma-La Sapienza, Italy	34	15 (0.61)	14 (0.57)	28 (0.65)	11 (0.54)	14 (0.68)	47 (17)	10 (10)
Kyoto University, Japan	34	15 (0.61)	48 (0.29)	11 (1.0)	13 (0.52)	12 (0.70)	74 (5)	8 (15)
Lund University, Sweden	34	15 (0.61)	56 (0.26)	8 (1.1)	24 (0.37)	24 (0.50)	76 (3)	10 (10)
North Carolina State University, USA	34	15 (0.61)	35 (0.35)	14 (0.93)	17 (0.45)	17 (0.58)	68 (7)	12 (6)
US Environmental Protection Agency, USA	33	19 (0.59)	56 (0.26)	11 (1.0)	26 (0.36)	21 (0.53)	76 (3)	11 (9)
Nanyang Technological University, Singapore	33	19 (0.59)	13 (0.61)	38 (0.57)	22 (0.39)	19 (0.55)	42 (18)	9 (13)

TP: total publications; SP: single institute publications; CP: inter-institutionally collaborative publications; FA: publication of the institute of the first author; RP: publication of the institute of corresponding author; %TP: share in publication; %CP: the percentage of inter-institutionally collaborative publications in total publications in each country; and R: rank.

(Ho, 2007). The title of an article always calls for much deliberation from authors and can provide important information to readers. Furthermore, the title, along with the author keywords, provides a reasonably detailed picture of the article's theme. 'Keywords Plus' which have been generated independently of the title or author keywords go into far more detail, describing the article's contents with greater depth and variety (Garfield, 1990a,b). In recent years, analysis of words in the paper title, 'Keywords Plus', and author keywords in different periods have been presented as information of research trends in aerosol research (Xie et al., 2008) and stem cell research (Li et al., 2009). Analysis of words in the abstract was also reported as a tool for worldwide volatile organic compounds research trends (Zhang et al., 2009).

Articles (4134) with records of author keywords in the SCI database were analyzed. There were 5764 keywords listed by authors, 3500 (61%) keywords were used only once, 833 (14%) keywords were used twice, and 380 (6.6%) keywords were used three times. The large number of once-only author keywords probably indicated a lack of continuity in research and a wide disparity in research focuses (Chuang et al., 2007). Only 1051 (18%) keywords were used more than three times, which showed that the mainstream research in solid waste was considered to focus on a small field. The top 20 author keywords for the study period are listed in Table 5, using 4-year intervals to minimize the year-to-year fluctuations. The most frequently used author keyword is "municipal solid waste" (378; 9.8%). This may be attributed to the search phrase "solid waste*." Except for "municipal solid waste," and "solid waste," "heavy metals" (202; 5.2%), "landfill" (200; 5.2%), and "anaerobic digestion" (170; 4.4%) were the three most frequently used author keywords. Solid waste research on heavy metals remained at a high level during the study period. Most of the top 20 author keywords were related to the following

Table 5
Top 20 frequency of author keywords used.

Author keywords	TP	93-08 (R) [%]	93-96 (R) [%]	97-00 (R) [%]	01-04 (R) [%]	05-08 (R) [%]
Municipal solid waste	378	1 (9.8)	1 (12)	1 (9.9)	1 (11)	1 (8.5)
Solid waste	274	2 (7.1)	2 (11)	2 (7.4)	2 (7.3)	2 (6.0)
Heavy metals	202	3 (5.2)	3 (7.5)	4 (5.2)	3 (6.7)	4 (4.5)
Landfill	200	4 (5.2)	4 (6.4)	3 (6.8)	4 (6.6)	5 (4.0)
Anaerobic digestion	170	5 (4.4)	5 (5.2)	10 (4.0)	14 (2.6)	3 (5.5)
Recycling	167	6 (4.3)	6 (4.9)	5 (5.1)	5 (4.1)	6 (3.6)
Leachate	144	7 (3.7)	6 (4.9)	5 (5.1)	7 (3.7)	11 (3.0)
Compost	140	8 (3.6)	8 (4.3)	7 (4.6)	8 (3.4)	9 (3.2)
Composting	138	9 (3.6)	9 (4.1)	7 (4.6)	13 (2.8)	8 (3.5)
Incineration	125	10 (3.2)	9 (4.1)	11 (3.9)	10 (3.2)	13 (3.0)
Fly ash	121	11 (3.1)	11 (3.8)	12 (2.3)	6 (3.9)	11 (3.0)
Adsorption	117	12 (3.0)	12 (3.5)	25 (1.5)	12 (3.0)	6 (3.6)
Waste management	109	13 (2.8)	12 (3.5)	29 (1.4)	16 (2.5)	10 (3.1)
Solid waste management	101	14 (2.6)	12 (3.5)	9 (4.3)	14 (2.6)	17 (1.9)
Solid wastes	101	14 (2.6)	15 (2.9)	22 (1.7)	10 (3.2)	17 (1.9)
Leaching	101	14 (2.6)	15 (2.9)	13 (2.2)	9 (3.3)	14 (2.7)
Biogas	80	17 (2.1)	15 (2.9)	18 (1.8)	18 (1.7)	15 (2.2)
Sewage sludge	65	18 (1.7)	18 (2.6)	13 (2.2)	19 (1.6)	26 (1.5)
Pyrolysis	64	19 (1.7)	19 (2.3)	18 (1.8)	17 (2.3)	36 (1.1)
Biomass	63	20 (1.6)	19 (2.3)	29 (1.4)	21 (1.5)	20 (1.8)

TP: publications in the study period and R (%): the rank and percentage of the "Keywords Plus".

Table 6
Top 25 frequency substantives in the title of articles, and in four 4-year periods.

Words in title	93-08 (R) [%]	93-96 (R) [%]	97-00 (R) [%]	01-03 (R) [%]	04-08 (R) [%]
Waste	2168 (38)	149 (21)	435 (42)	572 (40)	1012 (41)
Solid	1766 (31)	84 (12)	388 (37)	492 (34)	802 (32)
Municipal	1280 (23)	159 (23)	248 (24)	331 (23)	542 (22)
Landfill	444 (7.8)	41 (5.9)	80 (7.6)	105 (7.3)	218 (8.7)
Ash	411 (7.2)	27 (3.9)	63 (6.0)	115 (8.0)	206 (8.2)
Management	363 (6.4)	47 (6.7)	65 (6.2)	82 (5.7)	169 (6.8)
Organic	351 (6.2)	26 (3.7)	64 (6.1)	85 (5.9)	176 (7.0)
Incinerator	263 (4.6)	35 (5.0)	53 (5.1)	86 (6.0)	89 (3.6)
Fly	252 (4.4)	10 (1.4)	36 (3.4)	91 (6.3)	115 (4.6)
Leachate	248 (4.4)	20 (2.9)	52 (5.0)	50 (3.5)	126 (5.0)
Incineration	240 (4.2)	23 (3.3)	36 (3.4)	80 (5.5)	101 (4.0)
Treatment	229 (4.0)	22 (3.1)	40 (3.8)	50 (3.5)	117 (4.7)
Compost	220 (3.9)	26 (3.7)	41 (3.9)	66 (4.6)	87 (3.5)
Composting	218 (3.8)	20 (2.9)	42 (4.0)	50 (3.5)	106 (4.2)
Solid-waste	206 (3.6)	185 (26)	8 (0.76)	6 (0.42)	7 (0.28)
Metals	180 (3.2)	7 (1.0)	35 (3.3)	54 (3.7)	84 (3.4)
Assessment	177 (3.1)	10 (1.4)	25 (2.4)	42 (2.9)	100 (4.0)
Recycling	172 (3)	28 (4.0)	38 (3.6)	37 (2.6)	69 (2.8)
Evaluation	172 (3.0)	22 (3.1)	27 (2.6)	46 (3.2)	77 (3.1)
Combustion	167 (2.9)	18 (2.6)	41 (3.9)	47 (3.3)	61 (2.4)
System	157 (2.8)	17 (2.4)	26 (2.5)	38 (2.6)	76 (3.0)
Model	154 (2.7)	18 (2.6)	20 (1.9)	44 (3.0)	72 (2.9)
Sludge	149 (2.6)	6 (0.86)	27 (2.6)	27 (1.9)	89 (3.6)
Gas	146 (2.6)	8 (1.1)	29 (2.8)	37 (2.6)	72 (2.9)
Carbon	140 (2.5)	7 (1.0)	16 (1.5)	41 (2.8)	76 (3.0)

TP: the number of articles in the study period and %: the percentage of the source title.

methods: recycling (167; 4.3), landfilling (landfill, leachate and leaching) (445; 11.5%), composting (compost and composting) (278; 7.2%), and waste-to-energy (incineration, fly ash and pyrolysis) (309; 7.9%).

In the title analysis, prepositions, such as "of" and other meaningless words were excluded. After eliminating these words, the 25 most frequently used single substantives in the titles were analyzed also in four 4-year periods and are shown in Table 6. On average, almost all the substantives showed a gradual increase during the investigation period in pace with the growth of the number of articles. To some extent, the results were similar to the analysis of author keywords, except for the search word "solid" and "waste," "municipal" was the most frequently used substantive (1280; 23%), which was in accordance with author keywords analysis. Five substantives (1333; 23.4%) (incinerator, ash, fly, incinerator, combustion, and incineration) related to waste-to-energy, which indicates that energy recovery attracted much attention in recent years, followed by two substantives (692; 12.2%) (landfill and leachate) related to landfilling, and two substantives (438; 7.7%) (compost and composting) related to composting and recycling (172; 3.0%). The percentage of "solid-waste" reduced from 185 (26%) in 1993–1996 to 7 (0.28%) in 2005–2008, to some extent, because "solid waste(s)" replaced "solid-waste" in the title of recent articles. In addition, "assessment," "evaluation," "system," "model," "gas," and "carbon" were listed in the top 25 substantives in the title.

The distribution of the 'Keywords Plus' with its rank and percentage in different periods is shown in Table 7. "Heavy metals,"

Table 7
Top 20 frequency of 'Keywords Plus' used.

'Keywords Plus'	TP	93-08 (R) [%]	93-96 (R) [%]	97-00 (R) [%]	01-04 (R) [%]	05-08 (R) [%]
Municipal solid-waste	482	1 (12)	5 (3.5)	1 (7.2)	1 (10)	1 (15)
Solid-waste	262	2 (6.3)	23 (2.1)	10 (3.7)	2 (6.0)	2 (7.7)
Water	257	3 (6.2)	4 (3.9)	5 (5.1)	3 (5.2)	3 (7.4)
Fly-ash	226	4 (5.5)	1 (6.0)	3 (5.7)	5 (4.9)	4 (5.6)
Heavy-metals	219	5 (5.3)	5 (3.5)	2 (5.9)	4 (5.1)	7 (5.5)
Soil	205	6 (5.0)	3 (4.2)	7 (4.5)	6 (4.9)	8 (5.2)
Sewage-sludge	204	7 (4.9)	2 (4.6)	4 (5.5)	10 (3.7)	5 (5.6)
Behavior	172	8 (4.2)	33 (1.8)	9 (4.1)	8 (4.1)	10 (4.6)
Management	161	9 (3.9)	186 (0.35)	29 (1.8)	15 (2.7)	6 (5.6)
Combustion	157	10 (3.8)	23 (2.1)	10 (3.7)	9 (3.8)	12 (4.0)
Removal	153	11 (3.7)	186 (0.35)	55 (1.2)	11 (3.3)	9 (5.0)
Degradation	152	12 (3.7)	12 (2.8)	14 (2.7)	7 (4.5)	14 (3.5)
Adsorption	130	13 (3.1)	15 (2.5)	35 (1.6)	27 (2.0)	11 (4.3)
Emissions	130	13 (3.1)	5 (3.5)	14 (2.7)	12 (3.2)	18 (3.2)
Model	129	15 (3.1)	23 (2.1)	12 (3.5)	15 (2.7)	16 (3.4)
Sludge	128	16 (3.1)	12 (2.8)	21 (2.2)	14 (2.9)	15 (3.5)
Carbon	107	17 (2.6)	83 (0.70)	21 (2.2)	13 (3.0)	24 (2.7)
Kinetics	106	18 (2.6)	43 (1.4)	42 (1.4)	20 (2.2)	18 (3.2)
Speciation	106	18 (2.6)	33 (1.8)	16 (2.5)	23 (2.2)	21 (2.9)
Soils	106	18 (2.6)	15 (2.5)	6 (4.9)	17 (2.6)	35 (2.0)

TP: publications in the study period and R (%): the rank and percentage of the "Keywords Plus".

"fly ash," and "sewage sludge" were present in words in the title, author keywords and 'Keywords Plus' list, which might be identified as current solid waste research hotspots. Some words "water," "behavior," "degradation," "emissions," "kinetics," "speciation," and "soil(s)" that only appeared in the rank of the 'Keywords Plus' list describing the article's contents with greater variety. Generally, the ranking of most author keywords, words in the title and 'Keywords Plus' fluctuated only slightly, which showed that the related research was basically steady.

4. Conclusions

Based on 6680 solid waste publications dealing with SCI, this bibliometric study provides an overview of research in solid waste and identifies some significant points in the research throughout the investigation period. The following conclusions were drawn from this study:

(1) Solid waste related researches have significantly increased in the last 16 years. A power model and an exponential model were applied to illustrate the relations between cumulative number of articles and the year. Furthermore, based on the exponential model, it can be calculated that the number of articles in 2013 will be twice that in 2008.
(2) There were totally 860 journals distributed in the 112 subject category. The mainstream research on solid waste was in environmental sciences and environmental engineering fields, while increasing attention was paid to the field of biotechnology.
(3) The G7, with a longer tradition in research in this field, accounted for 50% of total world production. The USA, with the highest h-index of 39, contributed the most independent and international collaborative articles. China represented the highest growth rate, with a low h-index of 13.
(4) According to the analysis of the frequency of title-words, author keywords and 'Keywords Plus', the solid waste related research was basically steady and mainstream research was centered on the following methods: recycling, landfilling, composting and waste-to-energy.

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