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Bibliometric analysis of research trends on solid waste reuse and recycling during 1992–2016

Nan Li[a], Ruru Han[b,*], Xiaohui Lu[a]

[a] School of Information Management, Beijing Information Science and Technology University, Xiaoying East Road, Haidian District, Beijing, 100192, China
[b] School of Energy and Environmental Engineering, University of Science and Technology Beijing, 30 Xueyuan Road, Haidian District, Beijing, 100083, China

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ABSTRACT

A bibliometric analysis of solid waste reuse and recycling was performed to trace the research trends and hotspots based on the literature in Science Citation Index (SCI) database from 1992 to 2016. Research trends were explored in each 5-year period, and the social network analysis was conducted to analyze collaborations among authors and co-occurrence of keywords. Results showed a rapid increase in publication outputs with wide international collaboration. Developing countries contributed the significant growth during 2007–2016. Comprehensive journals, such as *Waste Management* and *Resources, Conservation & Recycling*, tend to be much influential. Based on analyses of dominant categories, high-cited papers and co-authorship network, hot issues and research trends could be summarized as follows: 1) e-waste and biodiesel production from waste oil began to get wide attention since 2002 and 2007. 2) A large gap was observed between developed and developing countries in C&D waste and organic fraction of municipal solid waste. 3) Sustainability, industrial ecology and informal recycling became attractive hotspots of solid waste management in developing countries since the period of 2002–2006. In summary, developing countries entered a rapid development period in the field of solid waste reuse and recycling. Perspectives of sustainability and industrial ecology, integration of informal recycling into formal system, and reinforcement of composting, anaerobic digestion and C&D recycling could be feasible options for integrated waste management system in developing countries.

1. Introduction

Advancement in material science and rapid development of industrialization and urbanization have led to huge quantity of solid waste (Korai et al., 2017; Tansel, 2016). According to 'Global waste management outlook', reported by United Nations Environment Programme (UNEP) and the International Solid Waste Association, the global generation of 'urban' wastes was estimated at around 7–10 billion tons per annum, and the amount per capita has risen distinctly over the last 50 years (Wilson et al., 2015). The 'urban' wastes mainly include municipal solid waste (MSW), commercial and industrial (C&I) waste, and construction and demolition (C&D) waste. The compositions of MSW include textiles, metals, glass, plastics, paper and organic materials. C&D waste often represents the largest proportion of total waste generated, which accounts for 34% of the urban waste generated within OECD countries, and mainly include concrete, masonry, wood and asphalt (Metin et al., 2003; Moh and Manaf, 2017). Adverse effects of solid waste mismanagement on environment and public health, have promoted the development of technologies for solid waste reuse and recycling (Brereton, 1996; Giusti, 2009; Hamer, 2003). Among various disposal technologies, incineration is the most common disposal option to recover energy and minimize the volume of solid waste. However, it is an option of lower conversion efficiency and higher cost compared with recycling (Morris, 1996). Composting is another attractive disposal method, which has been used to recycle organic matter back into the soil to improve soil structure and fertility for centuries (Imbeah, 1998). Moreover, some novel disposal and management technologies, such as fermentation, and thermochemical processes, developed rapidly in recent decades (Almeida, 2016; Walker et al., 2009).

Bibliometric analysis is a useful method to identify research trends and hot issues based on historic publications information (Bi, 2013). It is also used to evaluate research performance of institutions, researchers and journals, as well as the research fields (Wang et al., 2010). In recent years, some work related to solid waste has been done based on bibliometric analysis. H. Fu (Fu et al., 2010), H. Ma (Ma et al., 2011), and L. Yang (Yang et al., 2013), have evaluated research trends of solid waste based on SCI-E database during 1993–2008 1991–2010 and 1997–2011, respectively. Results showed that (1) recycling was one

* Corresponding author.
E-mail address: hanruru@126.com (R. Han).

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of the most concerned and common methods for solving solid waste problems; (2) Research between developing and developed countries presented a large gap; and (3) China yield a large number of publications but possessed a low h-index.

Therefore, we analyze related studies from 1992 to 2016 to explore (1) whether changes occurred in the last 5 years compared with the research before 2012, (2) leading countries and collaborations in both international and domestic, and (3) the research status, development trends and hot issues in the field of solid waste reuse and recycling. In this study, we provide an updated review of this field during 1992–2016, and conduct a comparison research with studies in each 5-year period based on conventional bibliometric methods and literature analysis tools. The co-authorship network analysis and co-occurrence of author keywords are performed for further understanding of the global research status and development trends. Moreover, the annual outputs, dominant categories, most influential journals, and leading countries and institutions are analyzed.

2. Methodology and data

2.1. Data

The Web of Science (WoS), developed by Thomson Reuters Scientific, is one of the most widely used database in such studies. It provides more consistent and standardized records and better graphics in citation analysis compared to other databases, and allows to download full citation records into a ".txt" file compatible with most of literature analysis tools, such as Bibexcel (Falagas et al., 2008; Newell and Cousins, 2015). Information on scientific was searched in the database of Science Citation Index Expanded (SCI-E), Social Sciences Citation Index (SSCI), Conference Proceedings Citation Index- Science (CPCI-S) and Conference Proceedings Citation Index- Social Science & Humanities (CPCI-SSH), which are all sub databases in Web of Science. The results were retrieved on January 12, 2017 with the search equation of "TS = ((solid waste*) AND (reuse or recycling or recycle))", which means records of publications containing terms of solid waste (or solid wastes) and reuse or recycle (or recycling) in the abstract, title, and/or keywords of a record. After eliminating records unrelated to the topic manually, mainly about wastewater treatment, a total of 6289 publications met the selection criteria. Data on author names, document type, language, publication years, addresses, subject categories, journals, title, author keywords, Keywords Plus, funding agency, and abstract has been collected for analyses.

2.2. Methodology

Social network analysis was widely employed to visualize and analyze the relationships between various nodes in bibliometric related studies, such as co-occurrence of keywords, academic collaborations among authors, institutions, and countries. The weighted undirected network model within the Netdraw was used to conduct the co-authorship and co-word network analysis and visualization, based on collaborations among researchers and co-occurrence of keywords in the same published papers. The size of nodes and weight of edges are proportional to the number of published articles and the times the authors have published together, respectively. The nodes are colored based on the modularity class they belong (Marinoiu et al., 2015). Co-word network and high-cited paper analyses were performed to trace research trends and possible hotspots.

The impact factor (IF) is one of the most popular indicators to measure the quality of research papers, the researchers who wrote those papers, and even the institutions they work in (Amin and Mabe, 2003). However, it only reflects the average citations per annum of articles published in last two years, and could not represent the citations of specific papers and identify the effect of highly cited articles. The h-index, defined by the h of N_p papers having at least h citations each and the other (N_p-h) papers have ≤ h citations each, can measure both the quantity and citations of publications, where N_p is the number of papers published over n years (Hirsch, 2005, 2010). Therefore, these two indicators were used to evaluate the quality and scientific research impacts of journals and counties. The contribution of different countries and institutions to the publications was estimated based on the affiliation of at least one author. We divided articles into "single institution article", "single country article", and "international collaborative article". The "single country article" was assigned if the authors were affiliated to different institutions within the same country. Articles that originated from England, Scotland, Northern Ireland, and Wales were grouped as the United Kingdom (UK).

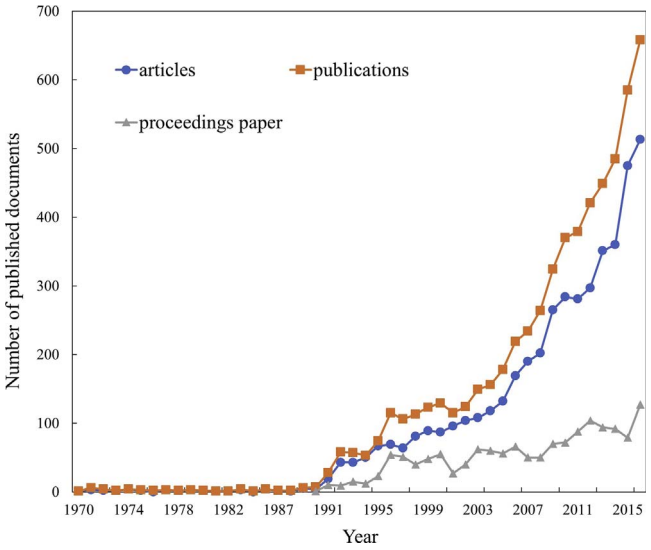

Fig. 1. Annual number of published documents in 1970–2016.

3. Results and discussion

3.1. General trends

The annual number of publications from 1970 to 2016 was presented in Fig. 1. Documents published during 1992–2016 will be analyzed emphatically owing to less convincing of insufficient data before 1991, which less than 10 records per year. As shown in Table 1, the number of publications related to solid waste reuse and recycling increased obviously, from 58 in 1992 to 658 in 2016, may be result of financial support from various funding agencies, which increased from 3.7% in 2006 to 58.2% in 2016. Meanwhile, the remarkable increase of international collaborative publications and average number of authors per document illustrated that the collaborations among authors increased continuously, especially the international collaboration. Moreover, the articles were the dominant type, which accounted for approximately 76.4% (4539) of the total number, and were used for further analysis together with proceedings papers (1444, 24.31%). English (5786, 97.40%) was the mainstream language, followed by Portuguese (61), German (28), Spanish (27) and Japanese (21).

3.2. Distribution of journals

The 5609 articles/proceedings papers were published in 1402 journals or conference. The top 10 productive journals, shown in Table 2, published approximately 26.8% papers of the total number. *Waste Management*, which incorporated with *Advances in Environmental Research* in 2005, published the most articles (386, 6.88%) with the highest h-index of 43. *Resources, Conservation & Recycling (RCR)* ranked second (261, 4.65%) in both number of articles and h-index of 39. *Waste Management*, *RCR* and *Waste Management & Research* are all

Table 1
Characteristics of annual publications in 1992–2016.

Year	TP	CP (%)	FP (%)	NR/TP	TC/TP	PG/TP	AU/TP
1992	58	3 (5.2)	1 (1.6)	10.6	12.1	11.5	2.6
1993	57	5 (8.8)	0 (0.0)	9.5	8.8	11.8	2.2
1994	53	6 (11.3)	0 (0.0)	18	18.9	11.3	2.7
1995	74	3 (4.1)	0 (0.0)	12.8	15.6	10.4	2.6
1996	115	3 (2.6)	0 (0.0)	11.6	12.1	8.3	2.4
1997	106	11 (10.4)	0 (0.0)	13.4	17.3	10.2	2.8
1998	113	9 (8.0)	0 (0.0)	18.3	18.4	11.6	2.9
1999	123	12 (9.8)	0 (0.0)	18.9	20.2	9.9	2.8
2000	129	11 (8.5)	0 (0.0)	18.8	23.1	9.5	3
2001	115	15 (13.0)	0 (0.0)	19.4	18.9	10.1	2.9
2002	124	18 (14.5)	0 (0.0)	18	23.3	9.1	3.5
2003	149	16 (10.7)	0 (0.0)	17.1	17.9	9.8	3.4
2004	156	13 (8.3)	0 (0.0)	20.4	18.6	9.4	3.4
2005	178	24 (13.5)	0 (0.0)	21.3	20.1	9.7	3.6
2006	219	38 (17.4)	8 (3.7)	23.7	20.1	9.5	3.5
2007	234	32 (13.7)	6 (2.6)	24.7	20.1	9.7	3.4
2008	264	41 (15.5)	51 (19.3)	24.8	17	8.5	3.5
2009	324	56 (17.3)	113 (34.9)	25.7	18.7	8.1	3.6
2010	370	68 (18.4)	149 (40.2)	28.4	12.1	8.3	3.6
2011	379	70 (18.5)	163 (43.0)	29	11.3	8.3	3.8
2012	421	70 (16.6)	193 (45.8)	28	9	8.6	3.9
2013	449	82 (18.3)	226 (50.3)	31.5	7.1	8.7	4
2014	485	111 (22.9)	261 (53.8)	31.6	6.1	8.8	3.9
2015	585	127 (21.7)	338 (57.8)	37.7	4.1	9.6	4.1
2016	658	152 (23.1)	383 (58.2)	37.6	1.2	9.6	4.3

Note: TP: total number of published documents; CP (%): international collaborative publications (percentage of the annual number); FP (%): funded documents (percentage of the annual number); NR/TP: average number of reference per document; TC/TP: average number of citation per document; PG/TP: average number of pages per document; AU/TP: average number of authors per document.

comprehensive journals that cover most solid wastes with various disposal and management methods. *Journal of Cleaner Production*, with the third highest impact factor of 5.715, began to publish articles related to solid waste reuse and recycling in 2003, mainly included papers about life cycle assessment, industrial symbiosis, environmental impact, and sustainability of solid waste management. *Journal of Hazardous Materials* and *Construction and Building Materials* focused on hazardous waste and C&D waste respectively, while *Bioresource Technology* published the most articles on composting and biodiesel production research. Moreover, eight out of the ten journals had a rapid increase in impact factor in last years, as shown in Appendix of supplement material, while *Waste Management & Research* and *Water Science and Technology* fluctuated within a narrow range slightly. It can be included that *Waste Management* and *Resources, Conservation & Recycling* were the most influential and vibrant journals in this field.

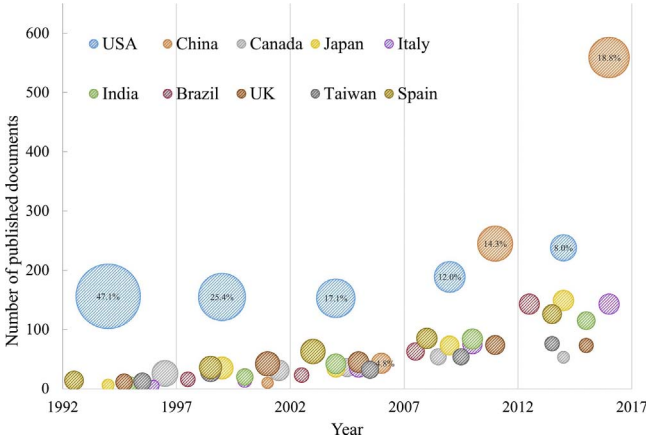

Fig. 2. Development trends of top 10 productive countries/territories.

3.3. Contribution of countries/territories

3.3.1. Statistics and trends

Statistical analysis of countries/territories showed that the top 10 productive countries, as displayed in Fig. 2 and Table 3, accounted for about 68.8% and 69.2% of the total publications and international collaboration publications, respectively. USA published the most documents in both single country and international collaboration during 1992–2016, with the highest h-index of 54. China ranked second in both publications and h-index, which was different from previous studies related to solid waste. Researchers from USA and China have been working in close collaboration with other countries, such as Canada, Brazil, Taiwan, and Japan, possibly owing to close academic exchanges among them.

The size of each bubble in Fig. 2 indicates the contribution of each country in each period. The USA was the most productive country during 1992–2006, followed by Canada, Spain and UK. While China surpassed the USA as the most productive country with the fastest growth rate during 2007–2016. Meanwhile, Brazil and India also achieved fast growth during 2007–2016. The reasons for this phenomenon were that developed countries started much earlier than developing countries, and have established relatively perfect management systems. USA, with the recycling rate more than 34% in municipal solid waste, has focused on solid waste recycling since at least the 1970s (Zhang, 2017). However, China and other developing countries experienced fast growth in last decade. Resources scarcity, rapid industrialization and urbanization were the main drivers for increased demand for secondary materials (Ezeah et al., 2013). According to the

Table 2
Top 10 productive journals with number of articles, impact factor, h-index, categories, and positions.

Journal	TP (%)	IF	h-index	Categories (Position)
Waste Management	386 (6.88)	4.03	43	Engineering, Environmental (Q1/12/49); Environmental Science (Q1/37/229)
Resources Conservation & Recycling	261 (4.65)	3.313	39	Engineering, Environmental (Q2/17/49); Environmental Science (Q2/60/229)
Waste Management & Research	218 (3.89)	1.803	24	Engineering, Environmental (Q3/28/49); Environmental Science (Q1/117/229)
Journal of Hazardous Materials	129 (2.30)	6.065	34	Engineering, Environmental (Q1/5/49); Environmental Science (Q1/13/229); Engineering, Civil (Q1/1/125)
Journal of Cleaner Production	111 (1.98)	5.715	21	Engineering, environmental (Q1/6/49); Environmental sciences (Q1/17/229); Green & Sustainable Science & Technology (Q1/5/31)
Bioresource Technology	88 (1.57)	5.651	28	Agricultural Engineering (Q1/1/14); Biotechnology & Applied Microbiology (Q1/14/158); Energy & Fuels (Q2/9/92)
Water Science and Technology	84 (1.50)	1.197	16	Engineering, environmental (Q4/38/49); Environmental sciences (Q3/169/229); Water resources (Q3/61/88)
Journal of Environmental Management	69 (1.23)	3.131	19	Environmental sciences (Q1/54/225)
Construction and Building Materials	51 (0.91)	3.169	17	Construction & Building Technology (Q1/8/61); Engineering Civil (Q1/11/125); Materials Science, Multidisciplinary (Q1/62/275)
Environmental Science & Technology	51 (0.91)	6.198	24	Engineering, environmental (Q1/4/49); Environmental sciences (Q1/12/229)

Note: TP (%): total number of published documents (percentage of the total publications).

Table 3
Information of the top 10 productive countries.

Country/ Territory	TP	R (%)	h-index	CP	SP	MC	MI
USA	894	1 (16.1)	54	219	675	China; South Korea; Canada	State University System of Florida; DOE
China	858	2 (15.5)	39	176	682	USA; Japan; Taiwan	Chinese Academy of Science; Tsinghua University;
Japan	324	3 (5.9)	28	105	219	China; Thailand	University of Tokyo
Italy	298	4 (5.4)	33	48	250	Spain; USA	Sapienza University Rome
India	272	5 (4.9)	30	36	236	South Korea	CSIR; IIT
Spain	269	6 (4.9)	31	74	195	Italy; USA; Brazil	CSIC
UK	245	7 (4.4)	37	92	153	Australia; Spain	Imperial College London
Brazil	245	8 (4.4)	20	44	201	Spain; UK; USA	Universidade De Sao Paulo
Taiwan	203	9 (3.7)	29	32	171	China; USA	National Cheng Kung University
Canada	200	10 (3.6)	29	56	144	USA; China	University of Guelph

Note: TP: total number of published document; R (%): rank (percentage of the total publications); CP: number of international collaboration publications; SP: number of single country publications; MC: major collaborate countries; MI: major institutions.

World Bank, China became the largest MSW generator since 2004. Facing this pressure, China has devoted considerable efforts to manage solid waste, and invested 210 billion to solid waste disposal projects during 2006–2010.

3.3.2. Collaborations among authors

Collaborations among authors, who published more than four articles, were shown in Fig. 3, and the isolated nodes were ignored. The largest component contains 86 authors, most of whom are Chinese, Japanese, Taiwanese and American researchers. N.B. Chang was the most prolific researcher with 36 articles (0.64%) and an h-index of 20, with the affiliations both of USA and Taiwan. N.B. Chang and his colleagues have conducted many research works on planning and strategies of solid waste management system. T. Fujita (13 articles, 0.23%) from National Institute for Environmental Studies in Japan had a close collaboration with Y. Geng from China on industrial & urban symbiosis for both pay attention to low-carbon industries in Asia. Meanwhile, he and his colleagues, including M. Fujii and S. Ohnishi, proposed a "smart recycling system" in recycling of organic solid waste. Strong edges within the component showed close collaborations among authors, and some of them have formed research communities, such as de Marco, I and his group from Spain. They mainly focused on the research of plastics pyrolysis. C. R. Cheeseman (15 articles, 0.27%), affiliated to Imperial College London was prolific in the studies of bottom ash management, mainly focused on sintering bottom ash to lightweight aggregate production. T.H. Christensen (14 articles, 0.25%) from Technology University of Denmark did much efforts on waste management based on life cycle assessment. Compared with T.H. Christensen, G. Finnveden mainly focused on method improvement of LCA.

3.4. Research tendency and hot issues

3.4.1. Categories

The 5609 articles/proceedings papers related to reuse and recycling

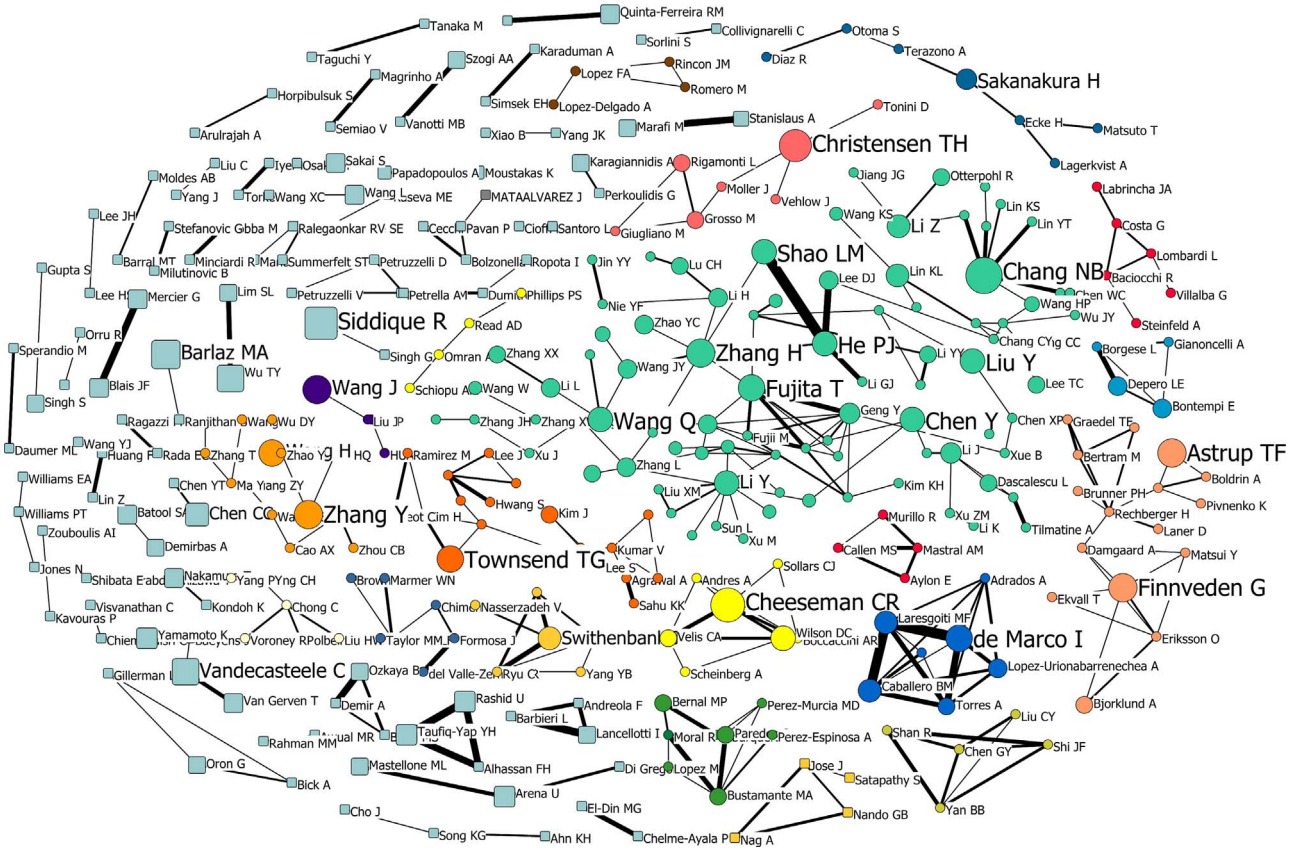

Fig. 3. Co-authorship network of solid waste reuse and recycling research during 1992–2016.

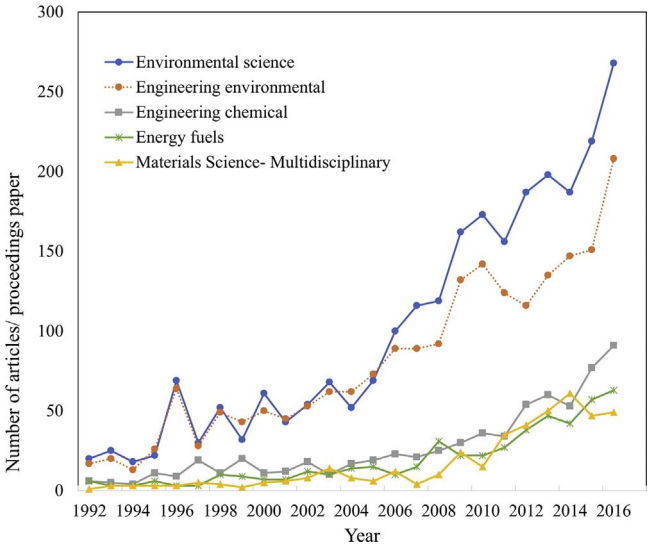

Fig. 4. The top five productive categories in 1992–2016.

of solid waste covered 153 subject categories in WoS. As shown in Fig. 4, environmental science (2500, 44.6%) and engineering environmental (2030, 36.2%) were the two dominant categories, which means that environmental impacts were the most concerned questions in the field of solid waste reuse and recycling. Engineering chemical (676, 12.1%), energy & fuels (482, 8.6%) and materials science-multidisciplinary (419, 7.5%) also increased rapidly in last decade, perhaps due to constant focus on chemicals, materials recycling and energy recovery from solid waste.

3.4.2. Word analysis

Through standardization of data processing, frequencies and co-occurrences of author keywords of 4390 articles were analyzed. The abbreviations, singular and plural forms of words were unified, and meaningless words and searched words, such as “analysis”, “solid waste”, “reuse”, and “recycle”, were ignored in succeeding analyses.

As shown in Table 4 and Fig. 5,“municipal solid waste” (357,8.13%) was the most frequently used word, followed by “waste management” (229, 5.22%). Most of the keywords about solid wastes or disposal methods have increased remarkably in frequency during the past two decades, due to the significant increase of publications with author keywords information in WoS. The strength of edges among author keywords illustrated that composting (160, 3.64%), anaerobic digestion (109, 2.48%), landfill (111, 2.82%), pyrolysis (93, 2.12%), and incineration (84, 1.91%) were the most conventional and popular disposal methods. Composting and anaerobic digestion were the most common disposal methods for food waste with the major production of biogas. Life cycle assessment (154, 3.51%), an important tool for ecological evaluation of products or processes, had a significant increase both in frequency and percentage, and was widely used in municipal solid waste management and environmental impact assessment (Mata and Costa, 2001). Electronic waste (49, 1.12%) and waste electrical and electronic equipment (WEEE) (47, 1.07%), emerging fractions of municipal solid waste, have become a major issue of concern due to its large volume and compositional complexity, and had an obviously increase since 2005 (Kang and Schoenung, 2005; Reyna et al., 2013). Moreover, biodiesel synthesis by transesterification from low-cost feedstock, such as waste cooking oil, has drawn much attention and increased sharply during 2012–2016. It was worth noting that compressive strength (41, 0.93%) and mechanical properties (40, 0.91%) are two main characteristics of recycled construction materials from various solid wastes, such as fly ash, C&D waste, and waste plastic. Industrial ecology (33, 0.75%) concepts such as cradle to cradle and circular economy have been considered leading principle for eco-innovation, aiming at “zero waste” society and economy where wastes are used as raw material for new products and applications (Mirabella et al., 2014).

3.4.3. Highly cited papers

Considering 29 highly cited papers categorized by Essential Science Indicators™ (ESI) database, and most frequently cited articles per year, a total of 38 papers were analyzed and displayed in supplement material. Four papers were published in *Waste Management*, three in *Energy Conversion and Management* and *Bioresources Technology*. From a national standpoint, eleven articles were published by authors from the USA, six from China, and four from UK. It was worth noting that all six highly cited articles from China were published in recent 5 years.

As shown in Table 5, the most highly cited article "Biodegradation of lignin in a compost environment: a review", with the citation of 425, was published in *Bioresource Technology* by M. Tuomela in 2000 (Tuomela et al., 2000). Among these top 10 highly cited publications, six articles were review or overview articles. Comprehensive reviews of basic concepts, characteristics and factors provided the basis for the following research. In terms of research area, disposal of organic waste through composting, biofuel production, e-waste, industrial sludge, scrap tire rubber, fly ash and catalysis were the most concerned topics. A. Demirbas analyzed the production, application, potential and limits of various biofuels in detail, as well as the global biofuel policy, economy and projections (Demirbas, 2008). Findings of evaluation of various solid acid catalysts and optimal reaction conditions made widely spread applications of biodiesel production from low quality feedstocks containing high free fatty acid possible in both academic and industrial scale (Jacobson et al., 2008). D. Dermatas identified the potential of utilization of fly ash for stabilization/solidification of heavy metal contaminated soils, and elucidated the mechanisms (Dermatas and Meng, 2003). Based on the atom utilization and E factor, comparison analyses of catalytic processes and conventional technologies were conducted to confirm the role of catalysis in waste minimization by Roger, A, especially the processes of catalytic oxidations and catalytic carbonylations (Sheldon, 1997).

3.4.4. Hot issues

The initial clustering structure was constructed based on previous analyses of dominant categories, high-cited papers, and high frequency words. Then, the possible hot issues were categorized into five categories based on co-word network in previous analyses:

1) Biodiesel production through transesterification/esterification from waste oil

Biodiesel has become an attractive, renewable and biodegradable energy source given the finite stock of fossil fuels and its negative impact on the environment (Mahmudul et al., 2017). Biodiesel production from low-cost feedstocks, such as vegetable oil, animal fats, waste cooking oil and microalgae through transesterification/esterification draw much attention since 2007. For the drawbacks of homogeneous catalysts in working with feedstocks contained high levels of free fatty acids, heterogeneous catalysts, such as acid zeolites, heteropolyacids, and ion-exchange resins, were the most concerned catalysts in recent years (Marchetti et al., 2008). In recent years, various novel heterogeneous catalysts were explored and applied to enhance biodiesel production. F.H. Alhassan, et al. from University Putra Malaysia have done much work on co-doping of metal nanoparticles as heterogeneous acid catalysts (Alhassan et al., 2014). Moreover, the application of inorganic solid waste, such as waste shells, waste concrete and cement, as low-cost solid catalyst draw much attentions, and showed high activity in esterification and transesterification reactions. Researches on novel catalysts to improve the production efficiency will remain one of the hotspots in the next few years, for its core support in biodiesel production.

Table 4
Frequency and percentage of author keywords in each 5-year period.

Keywords	1992–1996	1997–2001	2002–2006	2007–2011	2012–2016	TF
Municipal solid waste	26 (18.2)	37 (11.1)	40 (6.6)	111 (9.6)	143 (6.6)	357
Waste management	10 (7)	15 (4.5)	41 (6.7)	59 (5.1)	104 (4.8)	229
Composting	10 (7)	17 (5.1)	15 (2.5)	45 (3.9)	73 (3.4)	160
Life cycle assessment	1 (0.7)	9 (2.7)	18 (3)	39 (3.4)	87 (4)	154
Solid waste management	6 (4.2)	28 (8.4)	17 (2.8)	31 (2.7)	62 (2.9)	144
Landfill	8 (5.6)	15 (4.5)	26 (4.3)	32 (2.8)	43 (2)	124
Anaerobic digestion	10 (7)	9 (2.7)	17 (2.8)	27 (2.4)	46 (2.1)	109
Heavy metals	3 (2.1)	11 (3.3)	21 (3.5)	21 (1.8)	45 (2.1)	101
Pyrolysis	4 (2.8)	9 (2.7)	17 (2.8)	24 (2.1)	39 (1.8)	93
Leaching	2 (1.4)	5 (1.5)	14 (2.3)	28 (2.4)	39 (1.8)	88
Fly ash	1 (0.7)	3 (0.9)	19 (3.1)	21 (1.8)	41 (1.9)	85
Incineration	6 (4.2)	8 (2.4)	23 (3.8)	14 (1.2)	33 (1.5)	84
Biodiesel	0 (0)	0 (0)	0 (0)	11 (1)	64 (3)	75
Adsorption	0 (0)	4 (1.2)	7 (1.2)	15 (1.3)	40 (1.9)	66
Transesterification	0 (0)	0 (0)	1 (0.2)	11 (1)	45 (2.1)	57
Waste-to-energy	2 (1.4)	2 (0.6)	6 (1)	14 (1.2)	33 (1.5)	57
Sustainability	0 (0)	0 (0)	6 (1)	9 (0.8)	37 (1.7)	52
Bottom ash	0 (0)	2 (0.6)	6 (1)	13 (1.1)	29 (1.4)	50
Environmental impacts	0 (0)	5 (1.5)	4 (0.7)	16 (1.4)	25 (1.2)	50
E-waste	0 (0)	0 (0)	2 (0.3)	14 (1.2)	33 (1.5)	49
WEEE	0 (0)	0 (0)	1 (0.2)	11 (1)	35 (1.6)	47
Biogas	4 (2.8)	3 (0.9)	9 (1.5)	5 (0.4)	25 (1.2)	46
Food wastes	3 (2.1)	1 (0.3)	6 (1)	9 (0.8)	25 (1.2)	44
Sewage sludge	3 (2.1)	4 (1.2)	10 (1.6)	10 (0.9)	18 (0.8)	45
Compressive strength	1 (0.7)	1 (0.3)	3 (0.5)	10 (0.9)	26 (1.2)	41
Mechanical properties	2 (1.4)	3 (0.9)	0 (0)	15 (1.3)	20 (0.9)	40
Wastewater	0 (0)	4 (1.2)	8 (1.3)	12 (1)	16 (0.7)	40
Wastewater treatment	2 (1.4)	4 (1.2)	6 (1)	10 (0.9)	17 (0.8)	39
Recovery	1 (0.7)	3 (0.9)	6 (1)	6 (0.5)	22 (1)	38
Industrial ecology	0 (0)	0 (0)	2 (0.3)	14 (1.2)	17 (0.8)	33

Note: TF: the total frequency of author keywords in 1992–2016.

1) Pyrolysis of bio-refractory compounds and disposal of e-waste/ WEEE

Pyrolysis is a thermochemical decomposition of organic material at elevated temperatures in the absence of oxygen (or any halogen) (Zhang et al., 2017). It is a tertiary recycling technique in which organic polymers are converted into liquid oil, char and gases, and has been widely used to dispose various plastic waste, waste tires, wood waste, printed circuit board wastes and automobile shredder residues to recover organic matters, polymers, gasoline-range hydrocarbons, or

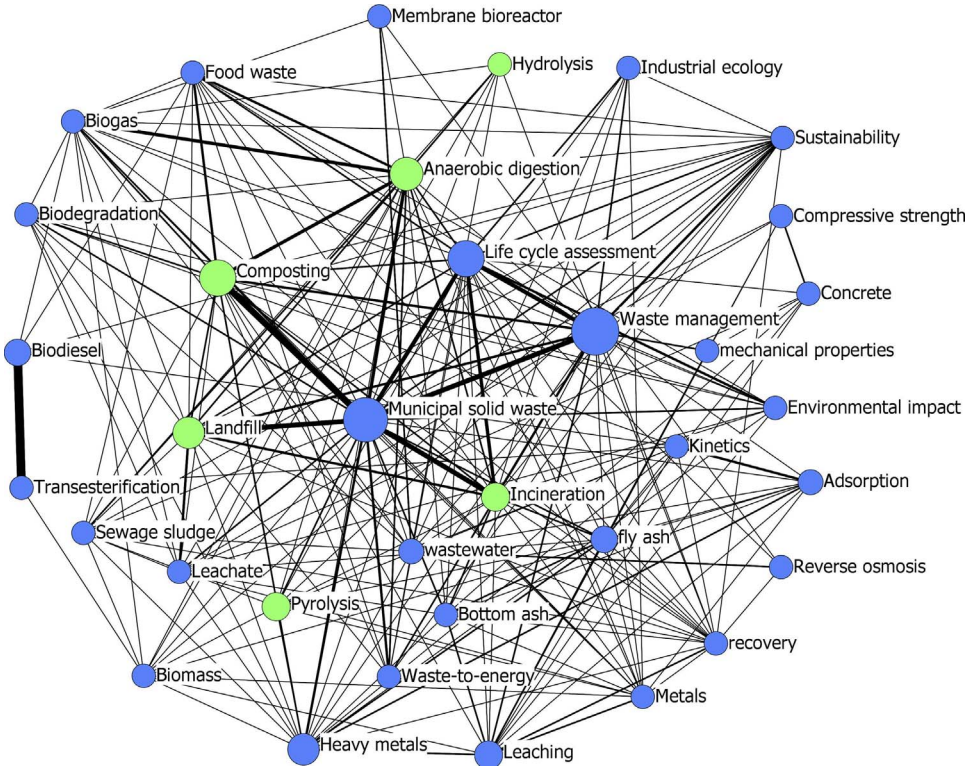

Fig. 5. Co-word network of author keywords.

Table 5
The top 10 highly cited publications during 1992–2016.

Title	Y	TC	Journal	Country
Biodegradation of lignin in a compost environment: a review (Tuomela et al., 2000)	2000	425	Bioresource Technology	Finland
Composting of animal manures and chemical criteria for compost maturity assessment. A review (Bernal et al., 2009)	2009	422	Bioresource Technology	Spain
Biofuels sources, biofuel policy, biofuel economy and global biofuel projections	2008	333	Energy Conservation and Management	Turkey
An overview on olive mill wastes and their valorisation methods (Roig et al., 2006)	2006	284	Waste Management	Spain
Properties of concrete containing scrap-tire rubber − an overview (Siddique and Naik, 2004)	2004	230	Waste Management	USA
An overview of utilization of slag and sludge from steel industries (Das et al., 2007)	2007	194	Resources Conservation and Recycling	India
Utilization of fly ash for stabilization/solidification of heavy metal contaminated soils	2003	194	Engineering Geology	USA
Solid acid catalyzed biodiesel production from waste cooking oil	2008	192	Applied Catalysis B- Environmental	Canada
Electronic waste recycling: A review of US infrastructure and technology options (Kang and Schoenung, 2005)	2005	192	Resources Conservation and Recycling	USA
Catalysis: The key to waste minimization	1997	187	Journal of Chemical Technology and Biotechnology	Netherlands

Note: Y: year; TC: total amount of the citations.

metallic materials (Chen et al., 2014). Composition of products of pyrolysis under different temperatures was the most concerned question during 1992–2001, and other factors influencing the yield and characterization of pyrolysis products were studied over the following years. Moreover, the microwave pyrolysis and catalytic pyrolysis became the most popular focus to improve the efficiency, quality and yield of high added value productions at low temperature and reaction times.

The Waste of Electrical and Electronic Equipment (WEEE) and electronic waste, popularly known as “e-waste”, mainly contain metals (40%), plastics (30%), and refractory oxides (30%) (Gramatyka et al., 2007). With the increase of discard amount of electronic appliance, recycling of e-waste and recovery of valuable materials have a great significance for potential environmental pollution and considerable value. Several studies have shown that pyrolysis is a promising technique in recycling of e-waste, and had obvious advantages over other method, such as acid washing, corrosion method and incineration. In the process of pyrolysis, the organic materials can be transformed and recovered as fuels or chemical raw materials, meanwhile the inorganic materials can remain unchanged and recycled in the following separation step (Zhou and Qiu, 2010). The improvement of leaching efficiency in the process of recovery of precious metals from waste printed circuit boards became the hotspot in disposal of e-waste. However, recovering pure chemicals economically is one of the insurmountable problems to implement practically, and will get worked through over the coming years.

1) Recycling and reutilization of C&D waste and incineration fly ash/bottom ash

A quantity of papers were related to C&D waste with terms of construction waste, demolition waste, concrete, cement, aggregate, although are not included in high-frequency words. Meanwhile, papers about incineration fly ash/bottom ash were categorized into the same cluster for their main reutilization to construction materials. As the bulk of C&D waste is inert, landfill and illegal dumpling were widespread in 1970s and 1980s, and are still typically in many developing countries at present. For example, recycling rate in China was estimated at 5% at 2013. However, recycling and reutilization of C&D waste, became a quite important economic and environmental deal for our societies, with increasing concerns about sustainable construction (Kucukvar et al., 2014; Rao et al., 2007). A number of C&D recycling projects have been implemented in USA, Canada, and Europe, such as large-scale C&D waste processing plants and sorting plants (Huang et al., 2002; Ulubeyli et al., 2017). Directive 2008/98/EC of EU has set up a minimum target of reuse, recycling, and material recovery of non-hazardous C&D waste at 70% by weight until 2020 (Directive, 2008). The C&D waste was mostly used in road foundations and embankment, which was considered downcycling, in the past decades (Vandecasteele et al., 2013). Whereas, recycling C&D waste as aggregates in new concrete draw much attention in recent years, as well as recycled waste glass or asphalt shingle as a raw material in the manufacture of cement. A few studies have focused on the acceptability and characteristic of concrete with various doping contents recycled aggregates in recent years, and demonstrated to be relatively high in compressive strength and tensile strength. Meanwhile, researches based on life cycle assessment showed the economic feasible and eco-friendly of reutilization of C&D waste.

Incineration is widely used as a thorough method to realize volume minimization and energy recovery (Margallo et al., 2013). Even with serious threats to the environment, such as leaching of hazardous substances, these ashes have the characteristics and properties to be recovered and applied in many application fields (Margallo et al., 2015). Many studies have reported the properties and potential of reuse incineration fly ash/bottom ash to construction materials (concrete, cement, glass, etc.), sub-base materials in road construction, adsorbent and agricultural applications. The thermal treatment method, such as vitrification, melting and sintering were popular to stabilize the characteristics of fly ash/bottom ash. Moreover, the environmental risk of construction materials with recycled substances or fly ash/bottom ash were investigated in recent years, especially leaching of hazardous substances. The improvement of purification technologies may be expected to recycle C&D waste and incineration ash efficiently.

It could be concluded that developed countries have devoted much effort to reuse and recycling of C&D waste, while most developing countries failed to management and still had low recycling rate. Leaching of recycled construction materials is the most concerned question and need to be settled in the next few years.

1) Anaerobic digestion and composting of biodegradation organic wastes

Biodegradation organic wastes include food waste, sewage sludge, landfill leachate and animal waste (Bonetta et al., 2014). Organic fractions of MSW composition differed among countries, which are significant higher in developing countries (average 50%–70%) than in developed countries. Composting animal wastes to high-quality organic fertilizer and soil improver was the most focused point in 1992–2001. While it had a broader application in household waste, vegetable waste and sludge since 2002. Moreover, recycling food waste and sludge waste to produce biogas and hydrogen with the process of anaerobic digestion has become increasingly popular in the past decade (Bari and Koenig, 2001).

The two-phase anaerobic digestion has been studied in many papers, and pyrolysis, hydrolysis, and ozonation were employed to upgrade the process of anaerobic digestion of food waste and sewage

sludge. To obtain added-value materials in agriculture, co-composting of the solid fraction of anaerobic digestants was employed. Meanwhile, the control of characterization during composting and the effect of compost on soil properties have been studied in recent years. It could be predicted that composting and anaerobic digestion will be popular in developing countries for their high organic fractions in the next few years.

1) Integrated waste management based on LCA.

The application of integrated solid waste management is important to prevent harmful effects on ecological environment, with basic strategies of source reduction, recycling and resource recovery. Life cycle assessment has been widely applied to support decision making about solid waste management. Sustainability was one of the major concerns in solid waste management systems, especially in developing countries in recent years (Elsaid and Aghezzaf, 2015). Waste management based on industrial ecology perspective, a new subject combines theories of ecology and sustainable development, began to spring up in recent decades. Meanwhile, socio-economic, health and environmental impact of informal sector recycling caused a hot discussed on solid waste management in developing countries (Ezeah et al., 2013). A quantity of studies focused on the evaluation of environmental performance and greenhouse gas emissions of various waste management options based on the method of life cycle assessment. Most suggested management scenarios, including increasing rates of materials recycling and energy recovery, had an enormous potential for greenhouse gas emission reduction, and seemed to be effective and environmentally friendly.

3.5. Limitations

In this work, publications outside of the WoS database and citations outside of the WoS-registered journals are neither included nor analyzed, which eliminated some influential articles. Research based on other databases, such as Scopus, Google scholar, to further validate findings of this study will be worthwhile in the further studies. Besides, a considerable amount of papers related to wastewater were searched, some of which were about wastewater treatment with recycled solid waste, while others had nothing to do with solid waste. For example, “Functionalized monolayers on ordered mesoporous supports” published in *Science*, and was mainly about a novel solid material used to remove heavy metal from waste streams. Manual screening of these irrelevant articles is difficult and time-consuming. Text mining tools have been proven to be adaptive for mining text data and extracting knowledge from document, and may help improve efficiency in future studies.

4. Conclusion

In this article, we provided a panorama to profile up-to-date research trends and hot issues of solid waste reuse and recycling, based on bibliometric analysis of publications in each 5-year period. Social network analysis was conducted to analyze the collaborations among authors and co-occurrence of keywords. A rapid increase was observed in publication outputs with wide international collaboration. Developing countries have contributed to significant growth during 2007–2016, while developed countries maintained slight growth relatively. China has surpassed the USA as the most productive country since 2007–2011, and had a remarkable improve in quality and influence in last 5 years. These articles were published in 1402 journals. Comprehensive journals, such as *Waste Management* and *Resource, Conservation & Recycling*, tend to be more influential than others, with largest number of publications and highest h-index.

Based on comprehensive analyses of dominant categories, highly cited papers, high frequency words and co-network, hot issues could be summarized as follows: 1) recycling of e-waste has been an emerging hot issue since 2002–2006, and pyrolysis was a popular alternative to recover valuable materials from e-waste. De Marco, I and his groups have done much effort in pyrolysis. 2) Biodiesel production from waste oil through transesterification/esterification has become another emerging hot issue since 2006–2011, and research on novel catalysts developed rapidly during 2012–2016. 3) Reuse and recycling of C&D waste and incineration fly ash/bottom ash in new construction materials were economic feasible and eco-friendly options. Developed countries have devoted much effort in C&D waste recycling, while China still present a low recycling rate. C. R. Cheeseman was a prolific author in incineration ash management. 4)Anaerobic digestion and composting of organic waste to fertilizer or biofuel production will be more popular in developing countries due to high organic fractions of MSW. *Bioresource Technology* has published most articles in this field. Moreover, 5) sustainable management, industrial ecology and informal sector recycling in developing countries were possible hotspots in integrated waste management.

In summary, solid waste management in developed countries is in a relatively advanced stage, while developing countries are in a rapid development period, and there is still a large gap between developed countries and developing countries in C&D management and organic fractions of MSW. Perspectives of sustainability and industrial ecology, integration of informal sector recycling into a formal system, reinforcement of composting or anaerobic digestion, and inquiries into concerns about C&D waste are expected to help improve solid waste management in developing countries. Moreover, biodiesel production from waste oil and recycling of e-waste were two emerging hot issues, and have been concerned in both developing and developed countries. Furthermore, studies based on other databases, such as Scopus, Google scholar, and comparison among which will be worthwhile to validate findings of this study. Meanwhile, novel analytic methods and tools, such as text mining tools, should be explored to improve the accuracy and efficiency of bibliometric analysis.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.resconrec.2017.11.008.

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