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State of the art on food waste research: a bibliometrics study from 1997 to 2014

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ABSTRACT

The interest for food waste (FW) in the scientific community has been growing consistently in the most recent years. This is reflected by the number of publications (journal articles and proceedings papers) which can be accessed in the Web of Science (WoS) database. However, lacking of systematic, chronological and synthesizing studies indicating how this field has evolved over time. The main objective of this paper is to consolidate the state of the art of research on FW, based on a bibliometrics study of articles published over the past 18 years. The results are discussed under the following perspectives: chronological distribution, countries, institutions, source titles, subject categories, and author keywords. It is found that the FW research has increased rapidly over past 18 years, most notably in the last 8 years. In total, 2340 research articles were published in 801 journals and in 161 WoS subject categories. The top 7 productive countries were analyzed herein. The predominance of Chinese institutions in terms of article count and a predominance of industrialized countries' institutions in terms of citation score were compared. Finally, based on keywords analysis, it comes to the conclusion that the clean energy, treatment and valorization, and management innovation have attracted extensive attention during the past decade.

1. Introduction

Food waste (FW) is organic waste discharged from various sources including food processing plants, and domestic/commercial kitchens, cafeterias and restaurants. According to Food and Agricultural Organization (FAO), nearly 1.3 billion tons of foods including fresh vegetables, fruits, meat, bakery and dairy products are lost along the food supply chain (FAO, 2012). Moreover, the amount of FW has been predicted to increase in the next 25 years due to economic and population growth, mainly in Asian countries. When food is wasted, problems do not end up at that point. More than 95% of the FW ends at landfill sites, where FW would be converted into methane, carbon dioxide and other greenhouse gasses. The impact of FW to climate change is catastrophic (Melikoglu et al., 2013). Furthermore, as a major burden to the environment, FW is the main source of decay, odor and leachate in collection and transportation due to its high volatile solids (VS; 85–95%) and moisture content (75–85%) (Han, 2004). Therefore, the research on FW has posed a serious economic and environmental concern along with an awareness of FW and has grown at the international level in present days. Increasing focus has been given to FW collection, treatment, minimization, and energy recovery (Bernstad Saraiva Schott and Andersson, 2015; Halloran et al., 2014). As an emerging research area, the concepts, techniques, management system of FW have changed dramatically, from oversimplified procedures, such as collection of no-preconditioned wastes disposal in landfills, to integrated and sustainable methods that incorporate reduction practices, pretreatment, and biological processes for energy recovery (Grimberg et al., 2015; Han and Shin, 2004). What's more, not only the ways to disposing the FW have been improved, but also the FW itself has evolved due to consumption level and food structure changes of the society in recent decades. Intensive researches have been carried out on various aspects, such as technology innovation (Bernstad and la Cour Jansen, 2012a), sustainable development (Vandermeersch et al., 2014), and life cycle assessment (Bernstad and la Cour Jansen, 2011). Meanwhile, these increasing studies were published in diverse journals of many subject categories. In addition, one several scientometrics study has been published to analyze the trends of solid waste and municipal solid waste (Yang

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et al., 2013), which has shown that FW is becoming a hotspot for the research on food security, environmental protection and resource utilization. Despite the growing numbers of academic literature, there is a lack of systematic, chronological and synthesizing studies indicating how this field has evolved over time and become as an emerging research area. To tackle this issue, a bibliometrics approach is used in this study, based on the quantitative analysis of peer-reviewed articles to (1) summarize the significant publication performances in FW research, (2) identify the research focuses and hotspots of FW research, (3) enable readers to identify the trajectories of research, (4) provide the reference for the decision-making of governments and other organizations in FW management, and (5)help in understanding key elements on the theoretical and practical contributions thus far as well as future challenges.

2. Material and methods

The ISI Web of Science (WoS) published by Thomson Reuters is considered to be the most important source of data for scientific bibliometric analysis (van Leeuwen, 2006). Therefore, WoS was chosen as the data source for the research in this paper. Besides, sub-field databases Science Citation Index Expanded (SCI-EXPANDED) and Social Sciences Citation Index (SSCI), Conference Proceedings Citation Index—Science (CPCI-S) and Conference Proceedings Citation Index—Social Science & Humanities (CPCI-SSH) were also used as the data sources in this paper. "Food waste*" or "kitchen waste*" or "food residue*" or "kitchen residue*" were used as the keywords to search titles, abstracts, and author keywords from 1997 to 2014. For the research on FW, author keyword and word cluster analysis were made using Microsoft Excel (version 2010). The Global Citation Scores (GCS) and Local Citation Scores (LCS) were acquired by using HistCite. The impact factor values from Journal Citation Reports (JCR) 2013 were also added for the corresponding identified journal titles.

3. Results and discussion

3.1. Document types, publication output

The distribution of document types identified by the WoS was analyzed, from which 8 document types were found. The article was the most frequently used document type, accounting for 84.6% of total publication, followed by proceedings papers (14%), reviews (4.4%), and others (meeting abstracts, editorial materials, news items, corrections, and letters). As the dominant type of document, articles and proceedings papers were then analyzed in this study.

Fig. 1 shows that FW publication increase over years. Before 2002, FW publication increased slowly over time, and was contributed by the major industrialized countries (USA, UK, Japan, Canada etc.) (Fig. 2). After 2002, the number of articles in peer reviewed journals increased rapidly, from 64 in 2002 to 437 articles in 2014, which suggests that the research on FW has attracted particular interest recently and has probably become one of the most active frontiers in waste management field.

3.2. Publication distribution of countries and institutes

The publication indicators for the top 7 most productive countries in FW research are presented in Fig. 2. China showed significant research influence followed by USA, South Korea, UK, and Japan. While USA was clearly leading in terms of publications output in FW before 2008, it was found a big gap between China and rest of the selected countries after 2011. The focus of the Chinese researchers on the areas of FW might be related to Chinese government policies and initiatives, in which the management of

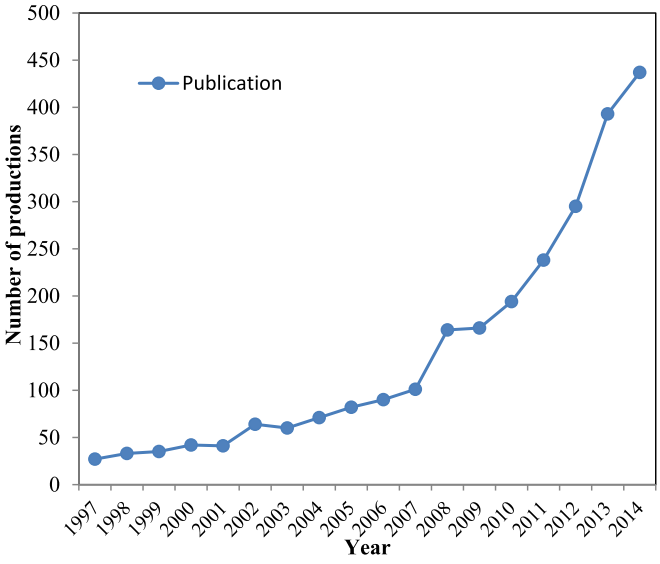

Fig. 1. Number of FW peer-reviewed publication increases over years.

FW is considered as a pivotal frontier of waste research. Similarly, the increasing trend in USA and UK could be due to the increased national interest to improve the FW management.

In term of the most relevant institutions investigation on the FW field. Table 1 shows publications and citation score along with the ALCS of the top 14 most productive institutions. The result indicates that Korea Advanced Institute of Science & Technology was ranked the 1st in terms of publication output, followed by Tongji University and Nanyang Technological University. In term of ALCS, Korea Advanced Institute of Science & Technology again had the highest score, demonstrating its preference in FW research. University of California, Davis and the Ohio State University ranked the 2nd and the 3rd respectively. The institutions from South Korea and USA were on the front ranking in LCS, GCS, and ALCS, which indicates the high average quality of their articles. The appearance of some highly cited but less productive institutions might suggest the highly relative importance of a few articles. The approach used in

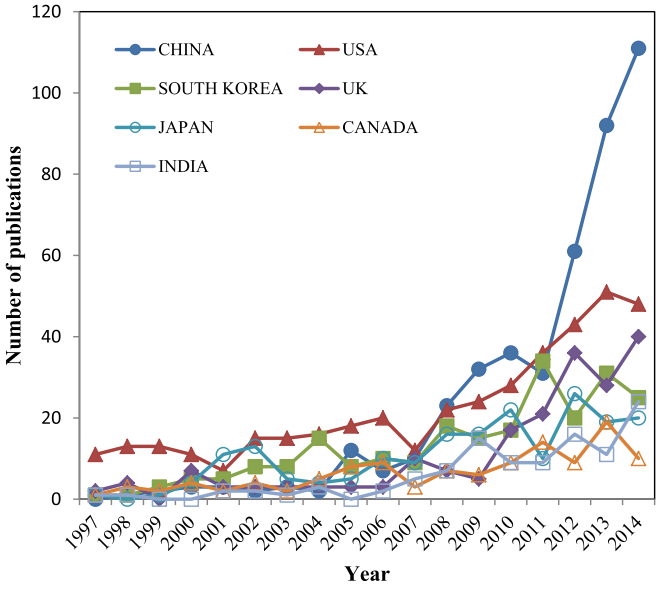

Fig. 2. The growth trends of the 7 most productive countries.

Table 1
Top 14 most productive institutes (1997–2014).

Institution	TP	LCS	GCS	R (ALCS)
Korea Advanced Institute of Science & Technology, South Korea	63	847	1600	1 (13.4)
Tongji University, China	51	155	497	9 (3.0)
Nanyang Technological University, Singapore	39	198	486	4 (5.1)
Tsinghua University, China	38	109	469	11 (2.9)
Korea Institute of Energy Research, South Korea	30	135	312	5 (4.5)
Beijing University of Chemical Technology, China	30	87	285	10 (2.9)
The Ohio State University, USA	28	182	897	3 (6.5)
Chinese Academy of Sciences, China	28	77	327	12 (2.8)
Washington State University, USA	25	95	474	6 (3.8)
University of Science & Technology – Beijing, China	24	35	188	14 (1.5)
University of California, Davis, USA	22	182	491	2 (8.3)
Harbin Institute of Technology,China	22	59	177	13 (2.7)
National Cheng Kung University, Taiwan	21	76	251	7 (3.6)
Universiti Putra Malaysia, Malaysia	20	66	298	8 (3.3)

TP total number of publications, *LCS* local citation score, which is the number of times cited by other papers in the local collection, provided by HistCite, *GCS* global citation score, which is the citation frequency based on the full WoS count at the time the data was download, provided by HistCite, *R (ALCS)* rank of average citation frequency of an article in the local collection.

our paper was successful in obtaining an approximation to the FW field as a science field pertaining to a scientific community. Also one should note that the Chinese institutions showed low ALCS among the selected institutions, which might indicate that there had been a considerable problem with the quality of articles published by researchers from China.

Interestingly, Singapore, Taiwan and Malaysia made their position among the top 14 institutions in the world, despite the fact these countries did not perform well in terms of publication output.

3.3. Publication patterns: source titles and subject categories

2340 articles were published in 801 journals listed in 161 subject categories in WoS. Table 2 lists the top 10 most productive journals with both citation score and IF. Major publication outlets of FW research include *Bioresource Technology*, *International Journal of Hydrogen Energy*, and *Waste Management*. These three journals also rank as top three in both TLCS and TGCS, demonstrating their significant influence in the field of FW research.

In addition, approximately 758 (32%) articles were published in 7 core journals. For comparison, the trends in the 7 journals with the greatest number of articles are shown in Fig. 3. In particular, a significant correlation in trends between *Bioresource Technology* and *Waste Management* was observed with a high similarity of trend lines. The possible reason for this correlation might be due to the fact that the management of FW has become an efficient method to accomplish the dual goals of waste reduction and energy production (Eriksson et al., 2014). The overall number of articles in *International Journal of Hydrogen Energy* increased, but with ups and downs, suggesting that utilizing FW to produce hydrogen through a biological route is still in its infancy. It is also noteworthy that the number of articles in *Water Science and Technology* has decreased in recent years.

For subject category analysis, 2340 publications (including 2 articles without subject category information) were analyzed statistically. As illustrates in Fig. 4, based on the continuous increase in the number of articles per category, FW research has increased in the categories of agricultural engineering, engineering chemical, especially in environmental sciences, energy fuels, engineering environmental, and biotechnology applied microbiology, while fluctuated slightly in chemistry physical.

3.4. Research emphasis: author keywords

The examination of author keywords in the present study indicates that 10,460 author keywords were used from 1997 to 2014. Only 375 (7%) keywords were used more than three times, indicating that mainstream research on FW focused on a small area. These keywords were calculated and ranked using six-year intervals to minimize year-to-year fluctuations.

Table 3 shows the 30 most frequently used author keywords along with their rankings and percentages. Through the analysis of the top 30 most frequently appearing author keywords, it is possible to draw the research trends from 1997 to 2014. Except for “food waste”, “kitchen waste”, and “waste” (the searching words

Table 2
Top 10 most productive journals (1997–2014) with the total number of papers, R (%), TLCS, TGCS, IF.

Journal	TP	R (%)	TLCS	TGCS	IF
Bioresource Technology	252	1 (9.9)	1187	3853	5.039
International Journal of Hydrogen Energy	156	2 (6.2)	1180	3860	2.930
Waste Management	143	3 (5.6)	489	1536	3.157
Water Science and Technology	73	4 (2.9)	248	955	1.212
Waste Management Research	64	5 (2.5)	154	440	1.114
Environmental Technology	36	6 (1.4)	45	166	1.197
Resources Conservation and Recycling	34	7 (1.3)	50	249	2.692
Compost Science Utilization	30	8 (1.2)	60	389	0.662
Process Biochemistry	25	9 (1.0)	215	681	2.524
Journal of Environmental Management	25	10 (1.0)	52	245	3.188

TP total number of publications, *R (%)* rank and percentage of total publication for a certain journal, TLCS total local citation score, which is the number of times cited by other papers in the local collection, provided by HistCite, *TGCS* total global citation score, which is the citation frequency based on the full WoS count at the time the data was download, provided by HistCite, *IF* impact factor, indexed in the Journal Citation Reports 2013.

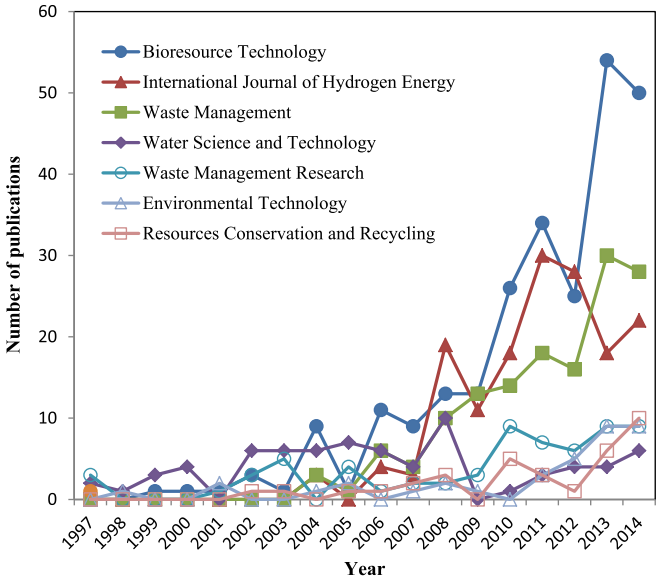

Fig. 3. The growth trends of the top 7 journals.

studied in the present work), most of the top 30 author keywords were related to the following aspects: treatment and disposal methods (anaerobic digestion, biohydrogen, composting, co-digestion, fermentation, dark fermentation) (708, 28%), energy products (biogas, methane, hydrogen, renewable energy) (279, 11%), operational condition (pH, volatile fatty acids, temperature, thermophilic, microbial community, pretreatment, hydrolysis, response surface methodology, optimization) (236, 9.3%), types of waste (Sewage sludge, municipal solid waste, organic waste, solid waste) (153, 6%), management (waste management, sustainability, recycling) (90, 3.6%), and evaluation methods (life cycle assessment) (28, 1.4%), which shows that the research on the treatment and disposal methods, energy products, and operational condition attracted more attention.

During the whole study period, research changes can be found. Apart from "food waste", the other three most frequently used

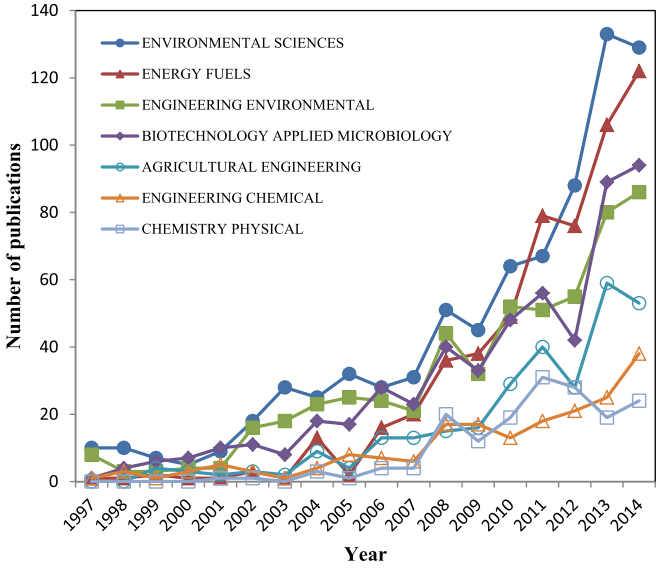

Fig. 4. The growth trends of the top 7 subject categories.

searching keywords were "anaerobic digestion" (246, 11.9%), "biohydrogen" (144, 7%), and "composting" (127, 6.2%). FW often contains high concentrations of easily degradable organic substances such as sugars, starches, lipids and proteins, thus it is suitable to be disposed by composting (Chang and Hsu, 2008; Kumar et al., 2010). Although composting is not a new waste disposal method, the characteristics of FW still bring an unique challenge to the researchers, since the basic knowledge of FW composting is inadequate for supporting successful processes with high efficiency (Lei and VanderGheynst, 2000). Besides that, the study about how to reduce environmental pollution emission and obtain desired final product with the operation cost (as cheap as possible), also attracts more attentions from governments and related researchers (Cekmecelioglu et al., 2005; Chang et al., 2006; Majlessi et al., 2012; Sundberg et al., 2013). Similarly, anaerobic digestion (AD) is proven to be an effective solution for FW treatment and valorization (Zhang et al., 2014). Compared with other traditional approaches for FW disposal, AD is very effective because of its limited environmental footprints (Cesaro and Belgiorno, 2014), high potential for energy recovery (Uçkun Kiran et al., 2014), and organic fertilizer or carrier material for biofertilizers (Kondusamy and Kalamdhad, 2014). Such positive aspects coupled with the recent concerns on rapid population growth, increasing energy demand, and global warming have promoted further research on the AD process development and optimization in order to enhance biogas production, achieve faster degradation rates and reduce the amount of final residue to be disposed (Carrère et al., 2010; Khalid et al., 2011; Mata-Alvarez et al., 2000; Shah et al., 2015), reflects in Table 3 that the ranking of "anaerobic digestion" increased stably from 3rd in 1997–2002 to 2nd in 2003–2014. Meanwhile, some AD-related keywords such as "biogas", "co-digestion", "pretreatment", "hydrolysis", and "optimization" also exhibited continuous high growth, which indicated that the optimized conditions, approaches, and main factors required for AD have attracted increasing interest in decades. On the other hand, the author keywords "composting" lost its research potential, since it has gradually decreased in the list of frequently used author keywords, which fell from 2nd in 1997–2002 to 4th in 2003–2008, and then descended to 6th in 2009–2014.

By comparison, "biohydrogen" had extremely high increasing rate in both ranking and percentage of all author keywords in the study period, as well as "hydrogen" (69, 3.4%), "dark fermentation" (39, 1.9%), and "renewable energy" (20, 1%). It is notable that the above-mentioned author keywords were not used before 2003, but after 2003, they went into a booming period, revealing that production of hydrogen through a biological route utilizing FW has represented an important area of FW research. As a sustainable energy source, hydrogen is a promising alternative to fossil fuels. It is a clean and environmentally friendly fuel, which produces water instead of greenhouse gases when combusted. Furthermore, it has a high energy yield (122 kJ/g), which is about 2.75 times greater than that of hydrocarbon fuels, and could be directly used to produce electricity through fuel cells (Lay et al., 1999; Mizuno et al., 2000). With increasing energy demand and concern about global climate change worldwide, utilizing renewable resources such as FW biohydrogen production would be a novel and promising approach for substituting fossil fuels while solving the waste disposal problem. Moreover, FW biohydrogen production has the potential to positively affect the global energy market for the production of energy from a cheap and renewable carbon source (Yasin et al., 2013). In addition, the frequently used author keywords "dark fermentation" indicated that the majority of the research on biohydrogen production from FW had been conducted under dark fermentation and it has increasingly attracted attention for industrial scale implementation (De Gioannis et al., 2013; Kim et al., 2008; Ren et al.,

Table 3
Top 30 most frequency of author keywords, 1997–2014.

Author keywords	TP	R (%)			
	1997–2014	1997–2014	1997–2002	2003–2008	2009–2014
Food waste	526	1 (25.5)	1 (24.8)	1 (26.3)	1 (25.4)
Anaerobic digestion	246	2 (11.9)	3 (7.0)	2 (8.5)	2 (13.5)
Biohydrogen	144	3 (7.0)	–	3 (7.3)	3 (7.7)
Composting	127	4 (6.2)	2 (14.6)	4 (7.1)	6 (5.0)
Biogas	112	5 (5.4)	–	11 (2.5)	4 (6.9)
Co-digestion	96	6 (4.7)	29 (1.3)	7 (3.4)	5 (5.4)
Kitchen waste	78	7 (3.8)	12 (1.9)	5 (4.8)	9 (3.7)
Methane	77	8 (3.7)	4 (3.2)	9 (3.2)	8 (4.0)
Hydrogen	69	9 (3.4)	–	13 (2.3)	7 (4.0)
Fermentation	56	10 (2.7)	29 (1.3)	6 (4.3)	12 (2.5)
Sewage sludge	49	11 (2.4)	6 (2.5)	7 (3.4)	13 (2.1)
Municipal solid waste	48	12 (2.3)	4 (3.2)	17 (1.6)	10 (2.5)
Dark fermentation	39	13 (1.9)	–	67 (0.7)	10 (2.5)
Organic waste	34	14 (1.7)	6 (2.5)	17 (1.6)	14 (1.8)
pH	33	15 (1.6)	12 (1.9)	11 (2.5)	22 (1.3)
Recycling	32	16 (1.6)	6 (2.5)	38 (0.9)	18 (1.6)
Volatile fatty acids	32	17 (1.6)	95 (0.6)	13 (2.3)	21 (1.4)
Waste management	31	18 (1.5)	29 (1.3)	67 (0.7)	15 (1.8)
Life cycle assessment	28	19 (1.4)	–	67 (0.7)	16 (1.7)
Temperature	27	20 (1.3)	12 (1.9)	17 (1.6)	25 (1.2)
Sustainability	27	20 (1.3)	95 (0.6)	252 (0.2)	16 (1.7)
Waste	27	20 (1.3)	95 (0.6)	26 (1.1)	20 (1.4)
Thermophilic	26	23 (1.3)	95 (0.6)	10 (3.0)	40 (0.8)
Microbial community	26	23 (1.3)	–	121 (0.5)	18 (1.6)
Pretreatment	25	25 (1.2)	95 (0.6)	26 (1.1)	22 (1.3)
Response surface methodology	24	26 (1.2)	–	26 (1.1)	22 (1.3)
Hydrolysis	23	27 (1.1)	95 (0.6)	26 (1.1)	25 (1.2)
Solid waste	22	28 (1.1)	29 (1.3)	26 (1.1)	29 (1.0)
Renewable energy	21	29 (1.0)	–	38 (0.9)	25 (1.2)
Optimization	20	30 (1.0)	95 (0.6)	38 (0.9)	29 (1.0)

TP total number of publications, *R* (%) rank and it's percentage in different period, – zero occurrence of the author keywords.

2011). Furthermore, much work has been done to help understand the most suitable conditions for hydrogen production, and the major focus has been on optimization of fermentation conditions like pH, temperature, volatile fatty acids, response surface methodology and pretreatment (Carlsson et al., 2012; Lin, 2004), which were more frequently used as author keywords in recent years. In conjunction with all biohydrogen-related author keywords, it is found that the study of biohydrogen production has undoubtedly played a dominant role in the current field of FW and attracted extensive attention during the past decade. On the other hand, the ranking and percentage of "methane" decreased during the studied period. Interestingly, the ranking of "thermophilic" fluctuated by a wide margin, which ranked 95th in 1997–2002, suddenly increased to 10th in 2003–2008, and evidently decreased to 40th in the period of 2009–2014, which could be ascribed to less attention being paid to this proven parameter in recent years (Chu et al., 2008; Shin, 2004).

Another important shift is the keywords "life cycle assessment", which could be rarely found in the publications before 2003, ranked 67th in 2003–2008, and soared to 16th in 2009–2014. The popularity of life cycle assessments (LCAs) in analyzing MSW management systems has been illustrated by the numerous published studies on the life cycle emissions of these systems, as well as the substantial number of LCA computer models addressing MSW management (Finnveden et al., 2009; Liamsanguan and Gheewala, 2008). Over the past decades, many institutions, as well as organizations such as the International Organization of Standardization (ISO) and the Society of Environmental Toxicology and Chemistry (SETAC) have boosted the development of the methodology used to enforce LCAs (Cleary, 2009). However, the standards are way general and do not give any detailed guidance in relation to use of LCA in specific areas, such as the management of FW. LCA of FW management is still a complex and emerging field as it includes both technical and biological processes (Bernstad and la Cour Jansen, 2012b). Several attempts were made to fill the gap between the general ISO standards and the complex questions arising when performing LCA within the FW field (Lundie and Peters, 2005). As LCA has been acknowledged as a tool enabling researchers to consider the full life cycle of MSW management system, and the holistic information provided by it has been used for decision support in MSW management planning (Zhao et al., 2009), LCA of FW management is considered to be a potential research hotspot in the field of FW under study.

Additionally, according to Table 3, it is found that both author keywords "sustainability" and "microbial community" had extremely high growth rates, and rose dramatically from the 252nd and the 121st in 2003–2008, to the 16th and the 18th in 2009–2014, respectively. Moreover, they had a prominent character: over 90 percent of the use of these words occurred in the recent 8 years, which implied these two important research directions has aroused particular interest recently and probably were representative to the frontier in the field of FW. "Sustainability" definitely pointed out that the sustainable development of FW management was the hotspot in the FW research and has grown to the international level: acknowledgment of food loss and waste was announced at the United Nations Conference on Sustainable Development (known as Rio + 20) as a component of the Zero Hunger Challenge (Phillips et al., 2013).The term of "Microbial community" pointed out that the characteristics of microbial community played important roles in fermentation processes. It is crucial to comprehensively understand the microbial behavior for the fundamental improvement of the fermentation process (Karakashev et al., 2005). Gradually, studies have focused on the relationship between microbial community characteristics and

metabolic functions during the biological processes (Gomez-Romero et al., 2014; Nitipan et al., 2014; Wan et al., 2013).

4. Conclusions

Based on 2340 publications from WoS, this bibliometric study provided an overview of the research in FW and identified some significant points in the research throughout the investigation period. The following conclusions were drawn from this study:

(1) Papers in FW research have significantly increased during the last 18 years, especially in last few years.
(2) The FW research output is distributed unevenly over all countries. The industrialized countries, owned a long tradition in this field, 4 out of the top 7 productive countries are from G7 countries. China has become the most productive country since 2008. Furthermore, the institutions from South Korea and the USA were on leading ranking in LCS, GCS, and ALCS, which indicated the high average quality of their articles. An interesting observation which also needs to be pointed out is Chinese institutions predominated in terms of article count while the industrialized countries' institutions performed better in terms of citation score. It could be inferred from this difference that articles written by scholars affiliated to industrialized countries are less in terms of quantity but more cited in terms of scientific impact. It was also found that there are 11 institutions from Asia, with the research focus of Asia in FW.
(3) In total, there are 2340 research articles in 801 journals listed in 161 WoS subject categories. Research on the fields of FW have mainly focused on agricultural engineering, engineering chemical, especially environmental sciences, energy fuels, engineering environmental, and biotechnology applied microbiology. All outputs have been concentrated in several journals like *Bioresource Technology*, *International Journal of Hydrogen Energy*, and *Waste Management*.
(4) Systematically analyzing the distribution of author keywords, it could be concluded that the research on treatment and disposal methods, energy products, and operational condition attracted more attention. Furthermore, many author keywords emerged after year 2003, in conjunction with biohydrogen-related author keywords such as "biohydrogen", "hydrogen", "dark fermentation", "renewable energy", "volatile fatty acids", "pretreatment", "response surface methodology", and "hydrolysis", it is found that the studies on biohydrogen production have undoubtedly played a dominant role in the current field of FW and attracted extensive attention during the past decade. The author keywords of "life cycle assessment", "sustainability", and "microbial community" have attracted particular interest recently and probably were representative to the frontiers in the field of FW. It also implies that the clean energy, treatment and valorization, and management innovation are the focus point of the decision-making and policy of FW management for governments in the future.

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