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# Research Output Analysis of Landfill Gas: A Global Perspective

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Landfill gas is a by-product of landfilling municipal solid waste and contributes to greenhouse effect. The paper analyzed the growth and development of landfill gas research productivity in the world for the period 1997-2012. All authors from 652 institutions contributed 649 publications out of which 592 were journal articles (including 52 proceeding papers), 23 reviews, 14 new items, 8 editorial materials, 5 letters, 5 meeting abstract, 1 correction and 1 reprint. About 4.47 % of publications were contributed by Technical University of Denmark, followed by North Carolina State University (2.16 %) and University of Calgary (2.16 %). Leading 20 authors in the area published at least 5 articles per person. An analysis of the title-words showed that "waste", "methane" and "emissions"were recent major topics of landfill gas research in the world. The results could help researchers understand the characteristics of research output and search hot spots of landfill gas field.

**Keywords: Landfill gas, HistCite, Methane.**

## INTRODUCTION

Municipal solid waste (MSW) has been and willcontinue to be a major issue facing countries worldwide[1]. This hold particularly true for developing countries, where the total amount of municipal solid waste has increased extremely rapidly due to rapid industrialization and increasing urban population. As human activities continue to add green house gases-carbon dioxide, methane, and nitrous oxides-to the Earth's atmosphere, global temperatures are expected to rise, causing the Earth's climates to change[2]. Landfill gas (LFG) which is essentially methane (50-55 %) and carbon dioxide (40-45 %) is released from municipal solid waste by biodegradation processes[3]. Both methane and carbon dioxide are typical green house gases (GHGs). Especially, methane ($CH_4$) is an important greenhouse gas because its global warming potential is 21 times more effective than that of $CO_2$[4]. Atmospheric $CH_4$ concentration has more than doubled during the past several 100 years and continues to rise[4]. Of the global anthropogenic $CH_4$ emissions, more than 10 % originate from municipal solid waste landfills[4]. There have been a number of published papers which have reviewed the trend of landfill gas emission reduction[5], extraction and purification technologies[6,7] and energy application[8,9]. However, the literature did not find any scientometric study on landfill gas.

HistCite developed by Garfield and colleagues[10-13] is an analytical and visualization tool which enables analysis of a subject and helps a researcher to identify the most significant work on a topic and trace its evolution. It also helps to identify highly productive and highly cited authors in any chosen area of research, particularly top and high impact journals and prominent institutions[14]. We attempted to use HistCite in this study to analyze the global research output of landfill gas. The total local citation score (TLCS) and the total global citation score (TGCS)[15] were also calculated in this paper. Total local citation score is the number of times anauthor's papers included in a collection have been cited by other papers also in the collection. Total global citation score is the number of times an author's papers included in a collection have been cited in the Web of Science. This analysis method has been applied in many areas. Osareh and Zare[16] used HistCite and MS Excel to study the scientific product of University of Tehran in Web of Science Database. In addition, Rajagopal *et al.*[14] analyzed the research output of pheromone biology in India. This analysis method has been accepted as an effective and efficient-approach to studying the output of narrow specialties.

This paper adopted HistCite to analyze the trends of research output of landfill gas during 1997-2012. The objectives of this study are as following: 1) To study the year-wise growth and languages of publications; 2) To study the document type-

wise contributions, authors, source of publications, institution with subdivision and subject domain with global citation score and local citation score; 3) To analyze the research trends of landfill gas.

## EXPERIMENTAL

The data used in this study were based on the database of the SCI published by Thomson Reuters Web of Science, Philadelphia, PA, USA. "Landfill gas*" was used as the string to search titles, abstracts and keywords from 1997 to 2012. And then all publications were downloaded from Science Citation Index. HistCite was used to process the data in the field of landfill gas research during years 1997-2012. The year of publication, journals and authors were analyzed and displayed in tables using HistCite. The Global Citation Scores and Local Citation Scores are examined to identify the pattern of research contribution on landfill gas research. The impact factor values from Journal Citation Reports (JCR) 2012 were also added forthe identified journal titles.

## RESULTS AND DISCUSSION

**Year wise distribution and languages of research output:** The publication output of landfill gas research in the study period 1997-2012 is summarized in Table-1. Journal articles, reviews, new items, letters, corrections, meeting abstracts, proceeding papers, reprint and editorial materials published in the 16-year period were considered for this study. It was observed that all authors contributed 649 publications out of which 592 were journal articles (including 52 proceeding papers), 23 reviews, 14 new items, 8 editorial materials, 5 letters, 5 meeting abstract, 1 correction and 1 reprint. The number of articles increased more than 3 times from 25 articles in 1997 to 75 in 2012. English was the most-frequently used language, making up 98.5 % (639) of all the published articles.

**Global and local citation score of landfill gas researchers:** Fig. 1 gives a view of the opening page of how the information is displayed in HistCite. The 649 publications have been cited by 7756 works. A global view of authors' work on

TABLE-1
CHARACTERISTICS OF RESEARCH OUTPUT ON LANDFILL GAS

| Year | Journal articles | Review | New items | Editorial material | Letters | Meeting abstract | Correction | Proceedings paper | Reprint | Total no. of papers | TLCS | TGCS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1997 | 19 | | 3 | 2 | 1 | | | 1 | | 25 | 117 | 386 |
| 1998 | 16 | | 1 | | | | | 3 | | 17 | 41 | 171 |
| 1999 | 26 | | | | | | | 3 | 1 | 27 | 102 | 368 |
| 2000 | 22 | 1 | 1 | | 1 | | | 4 | | 25 | 90 | 594 |
| 2001 | 24 | | 1 | | | | | 1 | | 25 | 118 | 452 |
| 2002 | 18 | 1 | 1 | | | | | 4 | | 20 | 66 | 724 |
| 2003 | 25 | 1 | | | | 1 | | 3 | | 27 | 113 | 366 |
| 2004 | 35 | 1 | | | | | | 9 | | 36 | 102 | 586 |
| 2005 | 32 | | 2 | 1 | | | | 3 | | 35 | 80 | 313 |
| 2006 | 35 | | 2 | | | 1 | | 4 | | 38 | 155 | 606 |
| 2007 | 41 | 4 | 1 | 1 | | 1 | | 4 | | 48 | 118 | 552 |
| 2008 | 53 | 3 | 1 | 2 | 2 | 1 | 1 | 3 | | 63 | 68 | 498 |
| 2009 | 54 | 1 | 1 | | 1 | | | 5 | | 57 | 78 | 407 |
| 2010 | 57 | 1 | | | | 1 | | 3 | | 59 | 41 | 224 |
| 2011 | 65 | 5 | | 2 | | | | 2 | | 72 | 17 | 170 |
| 2012 | 70 | 5 | | | | | | | | 75 | 2 | 31 |
| Total | 592 | 23 | 14 | 8 | 5 | 5 | 1 | 52 | 1 | 649 | 1308 | 6448 |

Total local citation score (TLCS), Total global citation score (TGCS)

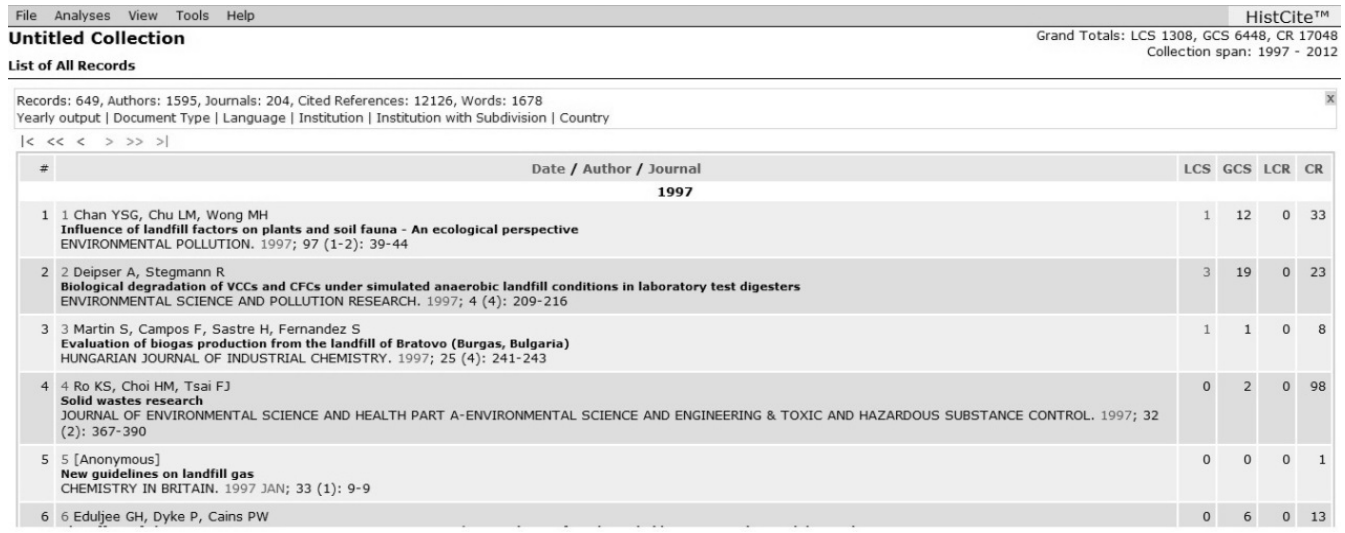


Fig. 1. A view of the HistCite output

landfill gas and the impact during a 16 year period could be obtained based on Table-1. For each publication, both local and global frequencies of citation were listed for analysis. It was found that total global citation score was much higher than total local citation score in the whole study period.

**Publication distribution by countries:** There were 60 articles without any author address information on the ISI Web of Science. Remained 589 articles were from 58 countries/ territories. The top 20 countries were ranked by the number of articles (Table-2). Two North and Central American countries, eleven European countries, six Asian countries/territories and Australia were ranked in the top 20. All of the seven major industrialized nations of the world (G7), USA, Japan, Italy, Germany, UK, Canadaand France were in the top 20 countries. USA ranked first in the list with the highest number of 139 works on the field. The pattern of domination in publication of the G7 has been found in most scientific fields[17], reflecting the high economy activity and academic level of these countries[18]. Two of the BRICS countries (China and India) ranked the third place and the ninth place, respectively.

TABLE-2
TOP 20 MOST PRODUCTIVE COUNTRIES OF ARTICLES DURING 1997-2012

| Rank | Countries | TA | Total local citation score | Total global citation score |
|---|---|---|---|---|
| 1 | USA | 139 | 392 | 1605 |
| 2 | Canada | 56 | 106 | 565 |
| 3 | PR China | 53 | 28 | 214 |
| 4 | UK | 51 | 126 | 1050 |
| 5 | South Korea | 40 | 104 | 350 |
| 6 | Germany | 36 | 141 | 596 |
| 7 | Denmark | 31 | 132 | 482 |
| 8 | Italy | 26 | 53 | 199 |
| 9 | India | 19 | 25 | 136 |
| 10 | Spain | 19 | 36 | 153 |
| 11 | Turkey | 19 | 16 | 95 |
| 12 | Austria | 17 | 40 | 247 |
| 13 | France | 14 | 42 | 193 |
| 14 | Sweden | 14 | 50 | 193 |
| 15 | Australia | 13 | 39 | 174 |
| 16 | Portugal | 13 | 22 | 175 |
| 17 | Finland | 12 | 31 | 136 |
| 18 | Japan | 11 | 3 | 30 |
| 19 | Thailand | 10 | 10 | 65 |
| 20 | Greece | 8 | 6 | 53 |

**Source-wise distribution of research output:** Out of 649 publications, 76 (11.7 %) publications were published in Waste Management and 52 (8 %) were published in Waste Management & Research and 53 (4.8 %) in Environmental Science & Technology (Table-3). All the top 20 journals located in England, USA and Netherlands.

Table-3 also presented that impact factors of the top 20 journals were between 1.193 and 6.018. It is to noted that the leading global citation scores were listed for Waste Management (673) followed by Bioresource Technology (535), Environmental Science & Technology (524), Waste Management & Research (520), Atmospheric Environment (267), Journal of Power Sources (231) *etc*.

**Author rankings:** Leading 20 authors in the field of landfill gas research were listed in Table-4. It was found that Kjeldsen P from Tech Univ Denmark had published the highest number of 21 works on the field followed by M.A. Barlaz, T.H. Christensen, C. Scheutz, J. Gebert, *etc*. Meanwhile, on the high score of global citations, it was observed that P. Kjeldsen's 21 works had 414 citations followed by M.A. Barlaz, J. Bogner, J. Gebert, C. Scheutz and M. Christophersen. Besides, on the high score of local citations, P. Kjeldsen had the highest score of 124 followed by M.A. Barlaz, M. Christophersen, J. Bogner and J.W. Park.

TABLE-3
LEADING JOURNALS PUBLISHING WORKS ON LANDFILL GAS RESEARCH

| Sl. No. | Journal title | TA | Total local citation score | Total global citation score | Publication country | Impact factors JCR-2012 |
|---|---|---|---|---|---|---|
| 1 | Waste Management | 76 | 177 | 673 | England | 2.428 |
| 2 | Waste Management and Research | 52 | 133 | 520 | England | 1.193 |
| 3 | Environmental Science and Technology | 31 | 173 | 524 | USA | 5.228 |
| 4 | Journal of The Air and Waste Management Association | 22 | 37 | 156 | USA | NF |
| 5 | Journal of Environmental Engineering-Asce | 14 | 42 | 123 | USA | 1.312 |
| 6 | Atmospheric Environment | 13 | 66 | 267 | England | 3.465 |
| 7 | International Journal of Hydrogen Energy | 11 | 4 | 101 | England | 4.054 |
| 8 | Journal of Hazardous Materials | 10 | 32 | 113 | Netherlands | 4.173 |
| 9 | Journal of Environmental Quality | 9 | 60 | 181 | USA | 2.324 |
| 10 | Bioresource Technology | 8 | 18 | 535 | England | 4.980 |
| 11 | Energy | 8 | 52 | 151 | England | 3.487 |
| 12 | Fuel | 8 | 13 | 49 | England | 3.248 |
| 13 | Journal of Power Sources | 8 | 28 | 194 | Netherlands | 4.951 |
| 14 | Renewable and Sustainable Energy Reviews | 8 | 14 | 49 | England | 6.018 |
| 15 | Water Air and Soil Pollution | 8 | 30 | 89 | Netherlands | 1.625 |
| 16 | Energy and Fuels | 7 | 18 | 65 | USA | 2.721 |
| 17 | Industrial and Engineering Chemistry Research | 7 | 19 | 102 | USA | 2.237 |
| 18 | Energy Policy | 6 | 10 | 46 | England | 2.723 |
| 19 | Environmental Monitoring and Assessment | 6 | 6 | 20 | Netherlands | 1.400 |
| 20 | Environmental Technology | 6 | 1 | 17 | England | 1.406 |
| | Other journals | 318 | 933 | 3975 | | |
| | Total | 649 | 1308 | 6448 | | |

TABLE-4
LEADING AUTHORS IN THE AREA OF LANDFILL GAS RESEARCH

| Sl. No. | Author | TA | Total local citation score | Total global citation score |
|---|---|---|---|---|
| 1 | P. Kjeldsen, Technical University of Denmark, Lyngby, Denmark | 21 | 124 | 414 |
| 2 | M.A. Barlaz, North Carolina State University, Raleigh, USA | 13 | 72 | 264 |
| 3 | T.H. Christensen, Technical University of Denmark, Lyngby, Denmark | 9 | 22 | 108 |
| 4 | C. Scheutz, Technical University of Denmark, Lyngby, Denmark | 9 | 40 | 171 |
| 5 | J. Gebert, University of Hamburg, Hamburg, Germany | 8 | 44 | 212 |
| 6 | S. Kumar, National Environmental Engineering Research Institute, Calcutta, India | 8 | 2 | 15 |
| 7 | J.W. Park, Yonsei University, Seoul, South Korea | 8 | 46 | 103 |
| 8 | J. Chanton, Florida State University, Tallahassee, USA | 7 | 35 | 77 |
| 9 | M. Christophersen, University Aalborg, Aalborg, Denmark | 7 | 62 | 164 |
| 10 | K.H. Kim, Sejong University, Seoul 143747, South Korea | 7 | 35 | 129 |
| 11 | S. Manfredi, Technical University of Denmark, Lyngby, Denmark | 7 | 13 | 65 |
| 12 | G. Achari, University of Calgary, Calgary, Canada | 6 | 17 | 30 |
| 13 | J. Bogner, Landfills Inc, Wheaton, USA | 6 | 61 | 214 |
| 14 | C. Chiemchaisri, Kasetsart University, Bangkok, Thailand | 6 | 3 | 16 |
| 15 | J. Feldmann, University of Aberdeen, Aberdeen, Scotland | 6 | 16 | 147 |
| 16 | J. Rintala, University of Jyvaskyla, Jyvaskyla, Finland | 6 | 18 | 97 |
| 17 | M. Borat, Istanbul University, Istanbul, Turkey | 5 | 4 | 14 |
| 18 | G. Demir, Yildiz Tekn University, Istanbul, Turkey | 5 | 4 | 9 |
| 19 | J.P.A. Hettiaratchi, University of Calgary, Calgary, Canada | 5 | 13 | 27 |
| 20 | C.E. Lee, Inha University, Inchon, South Korea | 5 | 7 | 24 |

**Leading institutions in landfill gas research:** Table-5 shows the leading institutions committing to landfill gas study. All 652 institutions have contributed the 649 publications over the 16-year period. Technical University of Denmark ranked first with 29 contributions (4.47 %) followed by North Carolina State University, University of Calgary, Florida State University and so on. USA, China and South Korea had the most institutions in the top 20.

TABLE-5
LEADING CHINESE INSTITUTIONS IN MUNICIPAL SOLID WASTE RESEARCH

| Sl. no. | Institutions | TA | Percent |
|---|---|---|---|
| 1 | Technical University of Denmark, Denmark | 29 | 4.47 |
| 2 | North Carolina State University, USA | 14 | 2.16 |
| 3 | University of Calgary, Canada | 14 | 2.16 |
| 4 | Florida State University, USA | 12 | 1.85 |
| 5 | University of Central Florida, USA | 12 | 1.85 |
| 6 | Yonsei University, South Korea | 10 | 1.54 |
| 7 | University of Florida, USA | 9 | 1.39 |
| 8 | University of Hamburg, Germany | 8 | 1.23 |
| 9 | US EPA, USA | 8 | 1.23 |
| 10 | Chinese Academy of Sciences, PR China | 7 | 1.08 |
| 11 | National Environmental Engineering Research Institute, India | 7 | 1.08 |
| 12 | Tsinghua University, PR China | 7 | 1.08 |
| 13 | University of Jyvaskyla, Finland | 7 | 1.08 |
| 14 | University of North Carolina, USA | 7 | 1.08 |
| 15 | Waste Management Inc, USA | 7 | 1.08 |
| 16 | Geosyntec Consultants, USA | 6 | 0.92 |
| 17 | Kasetsart University, Thailand | 6 | 0.92 |
| 18 | Landfills Inc, USA | 6 | 0.92 |
| 19 | Sejong University, South Korea | 6 | 0.92 |
| 20 | Tongji University, PR China | 6 | 0.92 |

**Analysis of title-words:** The titles of articles present the core information that the authors would like to express. Therefore, all of the single words in the titles of articles were analyzed for development trends of landfill gas. The percentages of top 20 title-words were listed in Table-6. Other than the terms "landfill" and "gas", used for searching,"waste", "methane", "emissions", "solid" and "municipal"were the most five frequently title-words used in the 16-year research period, which indicated that methane emission attracted great concern in landfill gas research. Methane is one of the most important GHGs types and contributes to global climate change. The explanation for this might be that methane emission has become a serious global problem and carbon emission reduction became a global hot study area during the past 16 years. In addition, "cover" and "energy" also ranked in the top 20. That was highly accorded with the studies on landfill cover[19] and landfill gas application for energy[6,9,20]. Totally, carbon emission control and renewable energy application were the most hot topics in the study period. The observed findings were highly accorded with some review papers[21,22].

TABLE-6
TOP 20 MOST FREQUENCY OF TITLE-WORDS

| Sl. no. | Title-words | TA |
|---|---|---|
| 1 | Landfill | 358 |
| 2 | Gas | 288 |
| 3 | Waste | 125 |
| 4 | Methane | 118 |
| 5 | Emissions | 81 |
| 6 | Solid | 75 |
| 7 | Municipal | 73 |
| 8 | Assessment | 41 |
| 9 | Compounds | 40 |
| 10 | Soil | 38 |
| 11 | Biogas | 37 |
| 12 | Energy | 37 |
| 13 | Oxidation | 36 |
| 14 | Cover | 35 |
| 15 | Organic | 32 |
| 16 | Analysis | 31 |
| 17 | Generation | 31 |
| 18 | Production | 31 |
| 19 | Leachate | 30 |
| 20 | Carbon | 29 |

## Conclusion

The HistCite based analysis of landfill gas research has shown how the field has evolved and has helped in identifying the institutions that are active and the journals in which they publish their works. The publication trend shows that research activities are growing in this area. Institutions such as Technical University of Denmark, North Carolina State University, University of Calgary, Florida State University finished the most publications on landfill gas research during the period of 1997-2012. Journals such as Waste Management, Waste Management & Research, Environmental Science & Technology, Journal of the Air & Waste Management Association and Journal of Environmental Engineering-ASCE published the most works on landfill gas research and most of above are high impact journals.

Our findings indicated that landfill gas management was becoming a hot issue during the past 16 years. Especially for the period after 2003, the output of landfill gas research increased rapidly. Totally, carbon emission control and renewable energy application were the hot topics in the study period. However, the research output on landfill gas research would be higher than those found indexed in the Web of Science as it is likely that many articles might have appeared in publications, including those journals not covered by Web of Science. For a comprehensive coverage of research output and analysis, multiple data sources need to be used.

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