
B.M. Gupta*, S.M. Dhawan**, Ashok Kumar*** and P. Visakhi****


Abstract

The present study examined 3468 global publications in e-waste research, as indexed in Scopus database during 2007-16. E-waste research registered an annual average growth rate of (20.90%) and averaged 13.65 citations per paper. Among broad subjects, environmental science accounted for the highest publications share (52.13%) in e-waste research, followed by engineering (28.81%), chemistry (12.95%), materials science (10.76%), and others. The top 20 productive organizations and authors accounted for (25.29%) and (16.49%) global publications share respectively and (44.37%) and (40.11%) global citations share respectively during the period. The global e-waste research (2537) is widely scattered across journals, with the top 15 most productive journals accounted for (42.81%) share of total output reported in journal medium during the period. Waste Management contributed the largest number of papers (254), followed by Environment & Science (132 papers), Journal of Hazardous Materials (101 papers), Waste Management & Research (91 papers), Resource Conservation & Recycling (89 papers), Chemosphere (71 papers), Science of the Total Environment (65 papers), etc. during 2007-15.

Key Terms: E-Waste Research, Scientometric, Global Publications, Bibliometrics

Introduction

Electronic waste, commonly referred as e-waste, is one of the fastest growing segments in the municipal solid waste stream. Already in 2005 it was estimated that waste electrical and electronic equipment (WEEE) constitutes about 8 per cent of municipal waste in developed countries and is one of the fastest growing waste components. According to the Step initiative “e-waste is a term used to cover all items of electrical and electronic equipment and its parts that have been discarded by its owner as waste without the intention of reuse.” Rapid product innovation, miniaturization and replacement, especially for information and communication technology (ICT) products and consumer equipment, are fuelling the increase of e-waste. An internationally-adopted measuring framework developed by the Partnership on Measuring ICT for Development estimates the total amount of e-waste generated in 2014 was 41.8 million metric tons (Mt), forecast to increase to 50 Mt in 2018.

According to the UN, more than 33% increase in electronic waste is expected in the coming four years. Major regions across the globe generating e-waste are the United States, followed by Europe and Asia-Pacific. By 2025, the developing world will generate double the developed world’s waste computers. Historically Asia has been a popular dumping ground, but as regulations have tightened in these countries, this trade has moved to other regions, particularly West Africa. Most developing countries lack the waste removal infrastructure and technical capacities necessary to ensure the safe disposal of hazardous waste. And e-Waste has been linked to a variety of health problems in these countries, including cancer, neurological and respiratory disorders, and birth defects.

The composition of e-waste is very diverse and differs in products across different categories. It contains more than 1000 different substances, which fall under ‘hazardous’ and ‘non-hazardous’ categories. Broadly, it consists of ferrous and non-ferrous metals, plastics, glass, wood and plywood, printed circuit boards (PCB), concrete and ceramics, rubber and other items. Iron and steel constitute about 50% of...
the E-waste followed by plastics (21%), non-ferrous metals (13%) and other constituents. Non-ferrous metals consist of metals like copper (Cu), aluminum (Al) and precious metals, e.g. silver (Ag), gold (Au), platinum, palladium, etc. The presence of elements like lead, mercury, and arsenic, cadmium, selenium and hexavalent chromium and flame retardants beyond threshold quantities of e-waste classifies them as hazardous waste 10.

**LITERATURE REVIEW**

Only few bibliometric studies, based on research publications and patents, had been conducted in the past in this area. Amongst such publication studies, Pérez-Belis, Bovea and Ibáñez-Forés11 analyzed the main areas of research on waste electrical and electronic equipment by offering a broader analysis of the relevant literature in this field published between 1992 and August 2014. The literature researched comprises 307 articles, analyzed according to the topic they focus on (WEEE management, WEEE generation, WEEE characterization, social aspects of WEEE, re-use of EEE or economic aspects of WEEE). In addition, it took into account the temporal evolution (globally and by topic), location of the study, categories and subcategories analyzed. Queiruga Dios and González-Beníto12 adopted a bibliometric analysis of the scholarly literature that has addressed the study of reuse of WEEE. It examined 32 papers on this topic, indexed up to 2014 in the Scopus database, and has identified trends and opportunities related to the what, how, and where of the research in this matter. The results show the need for further investigations on certain aspects of reuse in order to overcome the barriers that exist in different countries. In particular, further case studies are needed in countries that practice greater reuse. Amongst the studies based on patents, the WIPO13 report covers in detail patent applications and granted patents within the space of e-waste processing and the recycling and recovery of materials from consumer products at the end of their useful life. The patent landscaping process applied to the e-waste field has uncovered several interesting facets of the electronic waste industry. Specifically, the patent activity of global e-waste innovation points strongly to the commoditization of electronic waste; in particular as a source of high value materials, such as rare earth metals (e.g. lanthanum, neodymium and praseodymium) that are commonly used in modern electronic items. A similar trend is also shown for noble metals, in particular silver, gold and platinum. Dey & Jana focused on the e-waste patents filed in India14. The study revealed a good number of technologies developed by Indian institutions like Council of Scientific and Industrial Research, individuals belonging to different institutions of India and other foreign companies. Despite its economic importance, research on e-waste recycling has never been seen as a priority and gets little respect within companies in India. This study suggests that electronic brand companies in India are lagging rather than leaders in adopting new technologies and innovation on e-waste recycling.

**OBJECTIVES**

- To study the growth of global research output and of top 15 most productive countries in e-waste research and its citation impact
- To study and analyze global research output by broad subject areas and the dynamics of research growth and decline
- To study the production productivity and citation impact of top 20 most productive organizations and authors
- To study the modes of communication in digital library research and characteristics of high cited papers

**METHODOLOGY**

The study retrieved and downloaded 10-year global publication data on e-waste research from the Scopus database (http://www.scopus.com) covering the period 2007-16. Scopus is an online multidisciplinary publications and citations database by Elsevier on the science, technology, medical, social sciences and humanities covering 22,000+ titles. The search tags – “Keyword tag” and “Article Title tag”– duly clubbed with search term “Electronic Waste*” OR “e-waste*” or “Electric Waste*” and Boolean operator constituted the search string for global search on publications output on global e-waste research. This search string was refined with Pub year tag for limiting data search by time interval from 2007 to 2016. This main search strategy was finally applied for downloading global publication output data on e-waste research. Furthermore, by using appropriate analytical commands/ tags, such as “year”, “document type”, “source type”, “language”, “subject area”, “keyword”, “author name”, “affiliation”, “country/territory” and “source type” available in Scopus database, the authors analyzed and refined the publication output by publication year, document type, source type, language-wise, subject-wise, keywords, source title. The study also analyzed and refined publication output by significant authors and organizations, leading collaborative countries, and distribution by international collaborative publications. A number of raw and relative bibliographical indicators used to assess and understand publication growth and dynamics of digital library research included: growth rate, number of publications and international collaborative publications, citation per paper, h-index, etc. Among relative bibliographical indicators, we have used activity index and relative citation index.

**DATA ANALYSIS**

E-waste research published across the world cumulated to a total of 3468 publications in 10 years during 2007-16, registered 20.90% growth, up in its annual output from 118 in 2007 to 550 publications in 2016. Its 5-year output increased from 1284 in 2007-11 to 2184 in 2012-16, and registered 70.09% quinquennial growth. Of the total global publications output, 65.22% (2262) appeared as articles, 24.45% (848) as conference papers, 5.62% (195) as reviews, 1.76% (61) as book chapters and others less than 1% each: editorial (0.81%), short surveys (0.63%), notes (0.58%), articles in press (0.37%), letters (0.29%), books (0.14%), erratum’s (0.09%) and conference review (0.03%) during 2007-16. The research impact of e-waste research averaged 13.65 citations per paper since publication during 2007-16; its 5-year impact of e-waste research averaged 13.65 citations per paper during 2007-11 and 9.87 CPP in 2012-16 (Table 1).

<table>
<thead>
<tr>
<th>Publication Period</th>
<th>TP</th>
<th>TC</th>
<th>CPP</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>118</td>
<td>4212</td>
<td>35.69</td>
</tr>
<tr>
<td>2008</td>
<td>218</td>
<td>4791</td>
<td>21.98</td>
</tr>
<tr>
<td>2009</td>
<td>247</td>
<td>6438</td>
<td>26.06</td>
</tr>
<tr>
<td>2010</td>
<td>317</td>
<td>5549</td>
<td>17.50</td>
</tr>
<tr>
<td>2011</td>
<td>384</td>
<td>6767</td>
<td>17.62</td>
</tr>
<tr>
<td>2012</td>
<td>349</td>
<td>5599</td>
<td>15.04</td>
</tr>
<tr>
<td>2013</td>
<td>382</td>
<td>5257</td>
<td>14.48</td>
</tr>
<tr>
<td>2014</td>
<td>390</td>
<td>3743</td>
<td>9.60</td>
</tr>
<tr>
<td>2015</td>
<td>512</td>
<td>3275</td>
<td>6.40</td>
</tr>
<tr>
<td>2016</td>
<td>550</td>
<td>1738</td>
<td>3.21</td>
</tr>
<tr>
<td>2007-11</td>
<td>1284</td>
<td>21.62</td>
<td></td>
</tr>
<tr>
<td>2012-16</td>
<td>2184</td>
<td>19592</td>
<td>9.87</td>
</tr>
<tr>
<td>2007-16</td>
<td>3468</td>
<td>47349</td>
<td>13.65</td>
</tr>
</tbody>
</table>

**Table 1: World Publication Output in E-Waste Research**

1. T.Paper output, T.Citations, CPP=Citations Per Paper.
Top 10 Most Productive Countries in E-Waste Research

Top 10 countries in e-waste research, ranked on global publications share, include: China (30.39%), followed distantly by USA (14.68% share), India and U.K. (5.71% each), Japan and Germany (4.18% and 4.01%), Italy, France, Brazil and Spain (3.72% to 3.06%). Their individual global publication share ranged between 3.06% and 30.39%. While five-year global publications share of USA and Spain share declined by 1.58% to 4.77%, it increased by 0.06% to 2.14% in respect of other top eight countries. Together these top 10 countries cumulated 77.88% global publications share and 88.55% global citations share during the period. Their 5-year global publication share increased from 75.78% in 2007-11 to 79.12% in 2012-16. The e-waste research was conducted across 87 countries during the period: 42 countries contributed 1-10 papers each, 11 countries 11-50 papers each, 12 countries 51-100 papers each, 9 countries 101-200 papers each and 2 countries 509-1054 papers each. Four of top 10 countries registered relative citation index above the world average of 1.17: Spain (1.36), Italy, China and USA (1.21%) during 2007-16 (Table 2).

Subject Wise Distribution of Research Output

The global e-waste research output was distributed across nine sub-fields as per Scopus database classification. Environmental science has been found to be the most preferred area of research pursuit in e-waste research accounting for highest publications share (52.13%), followed by engineering (28.81%), chemistry (12.95%), materials science (10.76%), and others during the period. The research activity in e-waste research was dynamic during the period. The average research activity of a given discipline is rated as 100. Among 9 subjects, chemistry registered the highest impact of 21.54 citations impact per paper followed by environmental science (19.22), etc and the lowest in computer science (4.77) during 2007-16 (Table 3).

Significant Keywords

Around 58 significant keywords have been identified from the literature, which seek to highlight possible trends in e-waste research. These keywords are listed in Table 4 in the decreasing order of the frequency of their occurrence in the literature covering period 2007-16.

Profile of Top 20 Most Productive Global Organizations

Top 20 most productive global organizations in e-waste research contributed 25 to 147 publications each; together
they contributed 25.29% (877) global publications share and 44.27% (21011) global citations share during 2007-16 (Table 5).

- Six organizations registered their productivity above group average of 43.85: Guangzhou Institute of Geochemistry, China (147 papers), Tsinghua University, China (83 papers), Shanghai Jiao Tong University, China (73 papers), Ministry of Education, China (57 papers), Research Centre for Eco-Environmental Sciences, CAS, and China (55 papers) and University of Chinese Academy of Sciences, Beijing, China (53 papers) during the period.

- Eight organizations registered impact above the group average of 23.96 citations per publication during 2007-16: Hong Kong Baptist University (67.37), Sun Yat-Sen University, China (35.08), University of Ibadan, Nigeria (31.56), University of Chinese Academy of Sciences, Beijing, China (29.85), Shantou University Medical College Shantou, Guangdong, China (29.17), Guangzhou Institute of Geochemistry, China (29.06), Tsinghua University, China (28.02) and Research Centre for Eco-Environmental Sciences, CAS, China (26.18) during the period.

- Eight organizations registered h-index above the group average of 15.8: Guangzhou Institute of Geochemistry, China (38), Tsinghua University, China (31), Hong Kong Baptist University (24), University of Chinese Academy of Sciences, Beijing, China (24), Shanghai Jiao Tong University, China (23), Research Centre for Eco-Environmental Sciences, CAS, China (22), Shantou University Medical College Shantou, Guangdong, China (18) and Ministry of Education, China (16) during the period.

- Ten organizations contributed international collaborative publications share above the group average of 22.58%: The Royal Institute of Technology, Sweden (59.38%), Huazhong University of Science & Technology, China (53.85%), CNR Centre National de la Recherche Scientifique, France (40.0%), Shantou University Medical College Shantou, Guangdong, China (36.59%), University of Ibadan, Nigeria (32.0%), Politecnico di Milano, Italy (26.92%), Tsinghua University, China (25.30%), Ministry of Education, China (24.56%), Hong Kong Baptist University (23.68%) and Zhejiang University, China (22.86%) during the period.

- Eight organizations registered relative citation index above the group average of 1.78 of all organizations: Hong Kong Baptist University (4.94), Sun Yat-Sen University, China (2.57), University of Ibadan, Nigeria (2.31), University of Chinese Academy of Sciences, Beijing, China (2.19), Shantou University Medical College Shantou, Guangdong, China (3.69), Guangzhou Institute of Geochemistry, China (2.13), Tsinghua University, China (2.05) and Research Centre for Eco-Environmental Sciences, CAS, China (1.92) during the period.

- Profile of Top 20 Most Productive Authors

Top 20 most productive authors in the domain of e-waste research contributed 14 to 59 publications each. Together they contributed 16.49% (572) global publications share and 40.11% (18994) global citations share during 2007-16 (Table 6).

Six authors registered publications output above the group average of 28.6: B.X.Mai (59 papers), J.I. Luo (56 papers), J. Li (54 papers), Z. Xu (48 papers), X. Huo (38 papers) and S.J. Chen (36 papers) during 2007-16. Nine authors registered impact above the group average of 33.21 citations per publication: M.H. Wong (82.41), S.J. Chen (48.94), J. Fu (43.89), J.P. Wu (42.43), G. Sheng (42.08), B.X. Mai (37.34), O. Osibounjo (36.55), X.J. Luo (35.41) and H. Duan (34.93) during 2007-16. Nine authors registered h-index above the group average of 14.25 of all authors: B.X. Mai (26), S.J. Chen and X.J. Luo (24 each), J. Li (23), M.H. Wong (20), X. Huo (18), J. Fu and Z. Xu (17 each) and X. Xu (15) during 2007-16. Nine authors contributed international collaborative publications share above the group average of 25.87% of all authors: K. Medes (100%), L. Dascălescu (95.83%), M.H. Wong (59.26%), S. Tanabe (47.06%), O.A. Ogunselten (47.06%), X. Huo (39.47%), X. Xu (36%), X. Zheng (31.25%) and J. Li (25.93%).
during 2007-16. Nine authors registered relative citation index above the group average (2.43) of all authors: M.H. Wong (2.56) during 2007-16. These 58 high cited papers were contributed by 280 authors from 134 organizations across 25 countries; together they received 9586 citations, and averaged 167.5 citations per paper. The research productivity was the largest from China (23 papers), followed by USA (13 papers), Hong Kong (7 papers), U.K. (5 papers), Germany and Australia (4 papers each), India (2 papers), France, Italy, Japan, South Korea, Spain and Switzerland (2 papers each), Austria, Belgium, Brazil, Canada, Finland, Mexico, New Zealand, Nigeria, Norway, Portugal, Taiwan and Turkey (1 paper each). Amongst 58 highly cited papers, 16 were reviews and 42 articles. Among 58 high cited papers, 18 resulted from solo collaborative papers. The most significant organizations participating in high cited papers were: Guangzhou Institute of Geochemistry, China (8 papers), Hong Kong Baptist University (7 papers), Research Centre for Eco-Environmental Sciences, CAS, China and Tsinghua University, China (3 papers each), Shanghai Jiao Tong University, China, and together they contributed 42.81% (1086) of total output in journals medium during the period. Waste Management reported the largest number of papers (254), followed by Environment Science & Technology (132 papers), Journal of Hazardous Materials (101 papers), Waste Management & Research (91 papers), Resource Conservation & Recycling (89 papers), Chemosphere (71 papers), Science of the Total Environment (65 papers), etc. during 2007-15 (Table 7).

Highly Cited Papers

Only 58 (1.67%) of total 3468 papers in e-waste research received 100 to 542 citations each since their publication during 2007-16. These 58 high cited papers were contributed by 280 authors from 134 organizations across 25 countries; together they received 9586 citations, and averaged 167.5 citations per paper. The research productivity was the largest from China (23 papers), followed by USA (13 papers), Hong Kong (7 papers), U.K. (5 papers), Germany and Australia (4 papers each), India (2 papers), France, Italy, Japan, South Korea, Spain and Switzerland (2 papers each), Austria, Belgium, Brazil, Canada, Finland, Mexico, New Zealand, Nigeria, Norway, Portugal, Taiwan and Turkey (1 paper each). Amongst 58 highly cited papers, 16 were reviews and 42 articles. Among 58 high cited papers, 18 resulted from solo collaborative papers. The most significant organizations participating in high cited papers were: Guangzhou Institute of Geochemistry, China (8 papers), Hong Kong Baptist University (7 papers), Research Centre for Eco-Environmental Sciences, CAS, China and Tsinghua University, China (3 papers each), Shanghai Jiao Tong University, China,
Shanghai University, China and Sun Yat-Sen University, China (2 papers each), etc. The most significant authors participating in high cited papers were: M.H. Wong (7 papers), B.X. Mai, X.J. Luo and S.J. Chen (4 papers each), J.P. Wu, J. Fu and G. Sheng (3 papers each), etc. The 58 highly cited papers were published in 26 journals, with 9 papers in Environment Science & Technology, followed by Waste Management (8 papers), Journal of Hazardous Materials (5 papers), Environment International (4 papers). Science of the Total Environment and Resources, Conservation and Recycling (3 papers each), Applied Energy, Bio resource Technology, Chemosphere, Energy and Environment Science and Environmental Pollution (2 papers each), and 15 other journals with 1 paper each: Advanced Functional Materials, Advanced Materials, Building & Environment, CRIP Annals – Manufacturing Technology, Environmental Health Perspectives, Environmental Impact Assessment Review, European Journal of Operational Research, Materials Today, Minerals Engineering, Nano Letters and Waste Management Research.

**Conclusion**

This study provides a quantitative and qualitative description of e-waste research covering 10-year period from 2007 to 2016. The publications and citation data was sourced from Scopus database. E-waste research conducted across 87 countries registered 20.90% growth, cumulated a total of 3680 publications, and averaged 13.65 citations per paper during the period. The global publication share of top 10 countries ranged between 3.06% and 30.39%, and together they accounted for 77.88% share during the period. China ranks top with 30.39% global publication share, followed by USA (14.68% share), India and U.K. (5.71% each), Japan and Germany (4.18% and 4.01%), Italy, France, Brazil and Spain (3.06% to 3.72%) during 2007-16. Four of top 10 countries registered relative citation index above the world average of 1.17: Spain (1.36), Italy, China and USA (1.21% each) during 2007-16. Of the global output on e-waste research, 52.13% intersected with environmental science, followed by engineering (28.81%), chemistry (12.95%), materials science (10.76%), computer science (8.91%), chemical engineering (7.84%), energy and medicine (7.67% each) and physics & astronomy (6.92%) during 2007-16.

Top 20 most productive organizations in the world include 14 from China and 6 others from Hong Kong, Sweden, France, Italy and Nigeria. Top most cited organizations include 6 from China, one each from Hong Kong, and Nigeria. Top 20 most productive authors include 12 from China one each from USA, Hong Kong, Brazil, Australia, Nigeria, France, Algeria, and Japan. E-waste research contributed 58 highly cited papers, which received 100 to 542 citations each, cumulated 9586 citations, and averaged 147.5 citations per paper. China contributed the highest number of highly cited papers (23) followed by USA (13 papers), and others. Waste Management published the largest number of papers (254), followed by Environment Science & Technology (132 papers), Journal of Hazardous Materials (101 papers), Waste Management & Research (91 papers), Resource Conservation & Recycling (89 papers), Chemosphere (71 papers), Science of the Total Environment (65 papers), etc. during 2007-15. Collectively, the top 15 most productive journals covering e-waste research accounted for 42.81% share during 2007-16. That developed and emerging economies are fast recognizing the threat to human health and environment from electronic waste and are seriously involved in containing its impact through research efforts is evident from their major contribution to e-waste research accounting for 77.8% global publications share and leading e-waste research to a fast track growth by 21% per annum during 10-year period i.e. 2007-16. Despite their progress in addressing issues relating to collecting, recycling and processing e-waste, R&D research in e-waste is still not a national priority. E-waste research and management cannot be left to voluntarism. Legislative and policy driven approach is the need of the hour and that such initiatives must supplement R&D efforts to address all e-waste management issues, and in addition lead such efforts to create appropriate infrastructures and systems needed for the purpose.

**References**