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Research Article

Scientometric Analysis of Research on End-of-life Electronic Waste and Electric Vehicle Battery Waste

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ABSTRACT
Electronic sector is the one of the most rapid developing sector which is also contributing towards uncontrolled handling of waste flows. It not only poses threat to environment but also to public health due to adoption of improper recycling and disposal methods. One of the fastest classified branch of e-waste which has potential to grow in future is end-of-life electric vehicle batteries. This paper presents current body of literature available on two giant data bases i.e. Scopus and Web of Science, focussing on research on environmental impact of e-waste and electric vehicle battery waste. For this purpose two set of keywords are used: Set A (Generalised) -"Environmental Impact of Electronic waste having 1498 research documents on Scopus and 1009 on Web of Science and Set B (Specific) - "Environmental Impact of Electric Vehicle Battery waste" having only 85 and 64 research documents on Scopus and Web of Science respectively. USA, China and Germany are having max imum funded projects. The developing countries, lag behind drastically in terms of funded projects. This scientometric study thus draws the attention towards the urgent need of research in this area in order to minimize the resource depletion and maximize the sustainability.

Keywords: Environmental Impact, End-of-Life, Lithium-Ion, Electric Vehicle Battery Waste, Scopus, Web of Science.

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INTRODUCTION

The generation of e-waste is increasing exponentially with recent developments in IT sector and overall increase in demand of computers, laptops, mobile phone, washing machines, TVs and electric cars, electric busses, e-bikes etc. Also, the automobile sector will be flooded with electrical vehicles in large volume to curb air pollution and noise pollution but will again add to the quantum of e-waste generation per capita. In 2018, the global electric car fleet exceeded 5.1 million, up 2 million from the previous year and almost doubling the number of new electric car registrations, electric two/three-wheelers on the road exceeded 300 million by the end of 2018. Electric buses continued to witness dynamic developments, with more than 460 000 vehicles on the world's road, almost 100000 more than in 2017 (IEA, Global Annual Report on Electrical Vehicles, 2019). The People's Republic of China (hereafter "China") remained the world's largest electric car market, followed by Europe and the United States. Norway was the global leader in terms of electric car market share (46%). The global stock of electric two-wheelers was 260 million by the end of 2018 and there were 460 000 electric buses. In freight transport, electric vehicles (EVs) were mostly deployed as light-commercial vehicles (LCVs), which reached 250 000 units in 2018, while medium electric truck sales were in the range of 1 000-2 000 in 2018. In India a programme named FAME (faster adoption of manufacturing of electric vehicles) was launched by government in two phases i.e. phase I and II which aims in production and manufacturing of electric 4-wheeler, 3-wheeler, 2-wheeler and electric buses. These electric vehicles are loaded with batteries made up of Lithium-Ion and Lithium-polymer, due to their high energy per unit mass and charging capability. Lithium Ion battery is composed of few undesirable metals like graphite (16%), Cu (9%), Ni (4.3%), Ag (20.2%), Polymer (14%), Al (5.5%), and Electrolyte (3.5%)[1,2] convey the presence of Pb (33.1 mg/l), Cr (6.14 mg/l) Th (7.86), Co (278000 mg/l), Ni (2960 mg/l). Once these batteries go out of use, they should preferably re-used, reduced and recycled.

It is not possible to recycle Lithium-Ion Batteries without causing any Environmental Impact.[3] In Country like Australia, 98.3% of Lithium-ion portable batteries are landfilled.[4] The actual scenario of recycling and disposal of such waste product and their fate is still to be researched in extensive manner all over the world. To research in this area, a bibliometric survey is performed from two of the giant databases i.e. Scopus and Web of Science which enable us to evaluate the need of doing research on this particular problem along with existing research being done. There are few key points taken into consideration to generate the data analysis. The search analysis, for a set of generalized keyword result and specific keyword result, is been compared and presented. The paper focuses on bringing all related analysis and comparisons to bring an insight on literature review available with us in Scopus and Web of Science (the data used, are taken on 24th of Sep, 2020). Figure 1 shows the flow chart of the Scientometric study performed and the various analysis done.

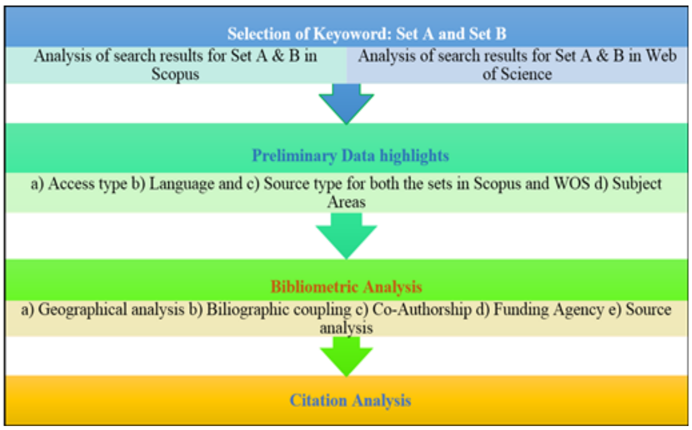

Figure 1: Flow chart for Bibliometric study and analysis.

DATA SOURCE AND METHODOLOGY

Source

The Scopus and Web of Science are one of the most giant data bases for research documents. Analysing any research area on these two data bases can provide a clear picture of research background pertaining to a particular domain. Various research collaborators, institutes and funding agencies could also be known through analysing the various searches on both the data bases. The first research document in the area of environmental impact of electronic waste appeared first in the year of 1973 and 1986 in Scopus and Web of Science respectively. Whereas research documents on environmental impact of electric vehicle battery waste appeared first in the year of 1988 and 1986 in Scopus and Web of Science respectively.

Keywords: Selection

There are two keywords taken into consideration. One is generalised set of keywords i.e. "Environmental Impact of Electronic waste"- Set A whereas the other one is based on Environmental impact of one of the type of e-waste i.e "Environmental impact of electric vehicle battery waste"- Set B. Table 1 summarizes the various combination of keywords searched and corresponding number of search results shown on Scopus and Web of Science. There are total 1498 Scopus and 1001 Web of science documents available for Set A while 85 Scopus and 64 Web of Science documents for Set B.

Table 1: Significant keyword and their combination. (Source: www.scopus.com and www.webofknowledge.com).

Keywords	Search Results	
	Scopus	Web of Science
Environmental and impact and of and electronic and waste - Set A	1510	1011
Environmental and Impact and of and electric and vehicle and battery and Waste- Set B	85	64
Environmental and impact and of and electronic and waste and flows	147	79
Environmental and impact and of and electric and vehicle and battery and waste and flows -	14	5

Primary Data highlights

A. Access Type

On entering the keyword for set A and B on Scopus and Web of Science, there is almost 80% reduction in documents which are not having open access for set A (Scopus). For documents in Web of Science, the percentage reduction for non-open access documents is 62.64% as Table 2. For set B, the percent reduction is 69.41% and 28.15% respectively for Scopus and Web of Science documents which are not having open access.

Table 2: Access type for Set A and B. (source: www.scopus.com and www.webofknowledge.com)

Sr. No.	Sets	Access	Scopus Publications	Web of Science
1	A	Open	152	191
		others	1358	818
2	B	Open	13	23
		Others	72	41

B. Language

More than 95% documents for both the set of keywords in both the data bases are in English language. There are few documents in Chinese language as well followed by French, Portuguese, and Spanish as Table 3.

Table 3: Language of documents for Set A and B. (source: www.scopus.com and www.webofknowledge.com)

Sr. No.	Languages	Set A		Set B	
		Scopus	Web of Science	Scopus	Web of Science
1	English	1474	985	83	64
2	Chinese	16	2	2	0
3	French	5	5	0	0
4	Portuguese	4	7	0	0
5	Spanish	4	8	0	0
6	German	3	0	0	0
7	Croatian	1	0	0	0
8	Italian	1	0	0	0
9	Japanese	1	0	0	0
10	Korean	0	1	0	0

C. Source Type

There are various sources of publication of documents in Scopus and WOS for set A and B. Most of the documents are either published as articles or as review paper followed by conference paper, editorial board etc. for Set A in both the data bases. For set B, most of the documents are published as articles and review paper in both the data set. There is no conference paper document till date for set B in WOS database as shown in Figure 2 and 3.

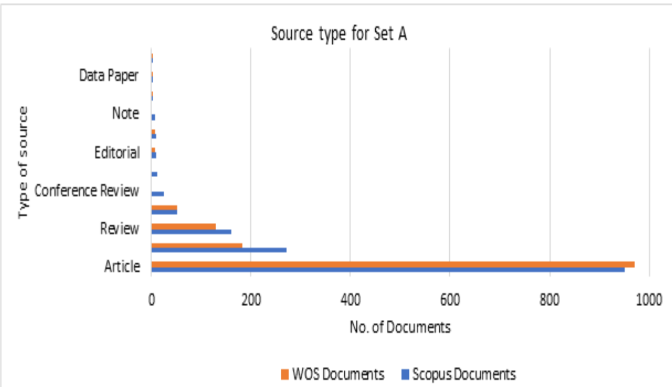

Figure 2: Type of source for Set A in both the data base. (Source: www.scopus.com and www.webofknowledge.com)

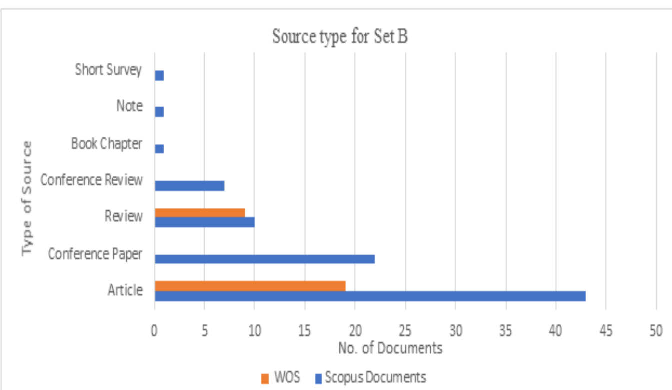

Figure 3: Type of source for Set B in both the data base. (Source: www.scopus.com and www.webofknowledge.com)

D. Subject Areas

In data base of Scopus, the main subject areas for set A are environmental sciences, engineering, energy, business management, chemistry, material sciences, chemical engineering and so on (Figure 4) and same subject areas are contributing areas for set B as well. The variation is only in terms of percentage total contributed by each subject area i.e. engineering science contributes 39% of the total value for set A while, 28% for set B.

The data base of web of science depicts that for set A, the contributing areas are environment science ecology, engineering, public environmental occupation, business economics, energy fuels, toxicology and so on in the

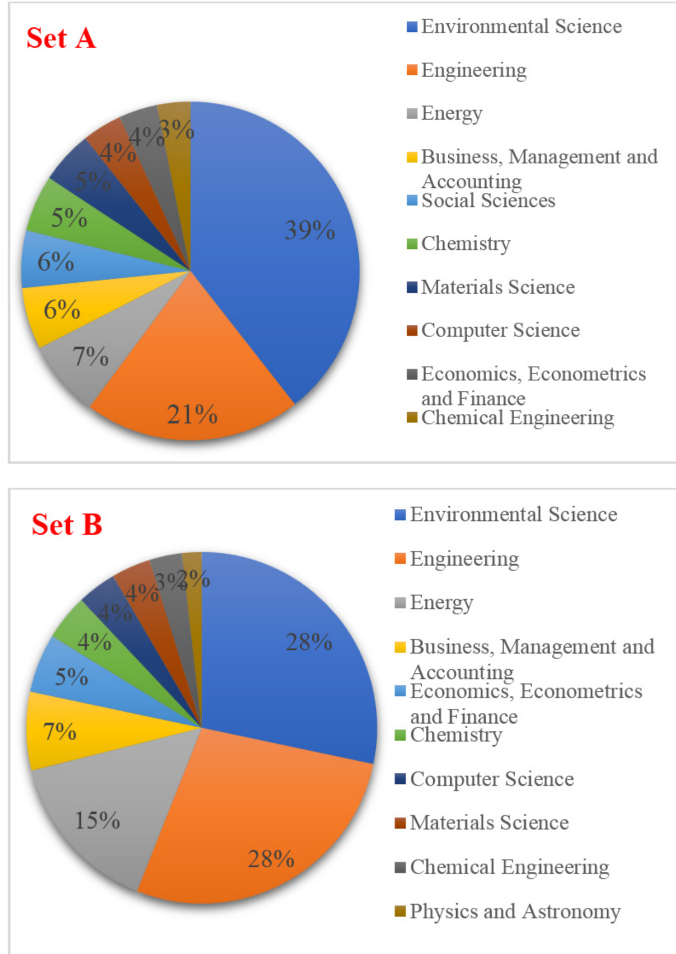

Figure 4: Subject areas in Scopus for Set A and B. (source: www.scopus.com and www.webofknowledge.com)

decreasing order. For set B, the predominant research areas in scopus are: Environmental Science and Ecology, Energy fuels, Science and technology, chemistry, computer science, telecommunications, business economics, electrochemistry, material sciences etc. as Figure 5. Public environment occupation has 13% weightage for set A i.e. environmental impact of e-waste and the main reason of this subject area is due to the fact that illegal recycling market has caused occupational hazard and human health impacts. Since, Electric vehicle batteries, it recycling and probable occupational hazard which it can cause is till unexplored area, hence public environment occupation is not a subject area for set B.

Bibliometric Analysis

Geographical Analysis

The satellite images are obtained by using Goggle i-map creator software as shown in Figure 6 (a) and (b) so as predict about countries which are already working on the topics with set A and set B respectively from database of Scopus. The number of countries and the corresponding number of documents which they have produced in much higher in

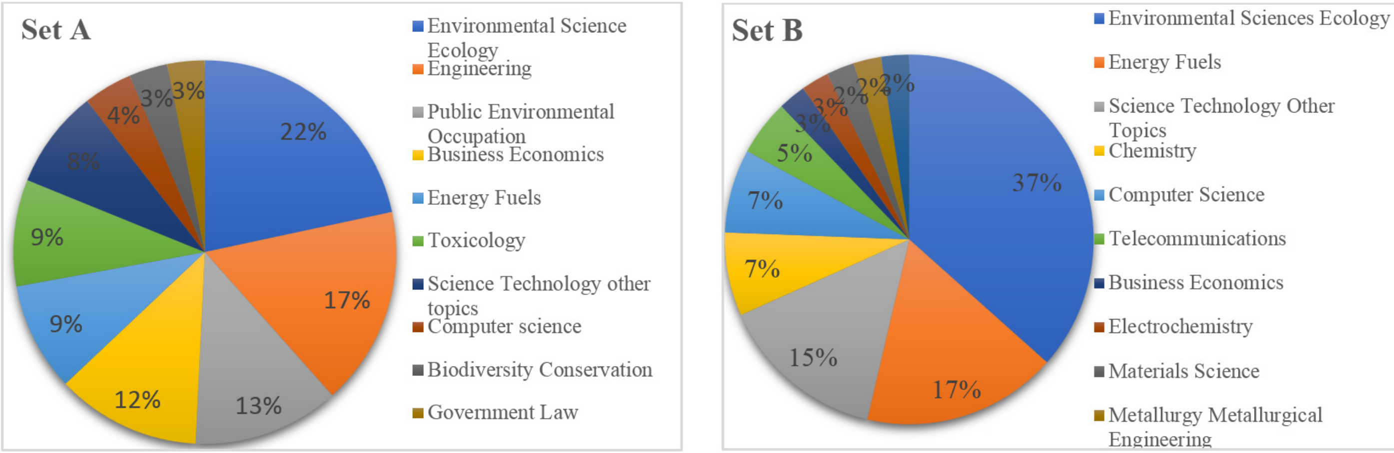

Figure 5: Subject areas in Web of Science for Set A and B. (source: www.scopus.com and www.webofknowledge.com)

Figure 6: a) Geographical Analysis for Set A.

Figure 6: b) Geographical Analysis for Set B.

numbers for Set A in comparison with Set B. Figure 6 a and b shows top 10 countries with research work in scopus and web of science for set A and set B respectively. China, US and UK are the most active countries in terms of research work in both the sets followed by Italy, India, Germany, Japan, Belgium, and France. For Set B, China, US, Germany and Uk top the list and developing countries like India has still no scopus of web of science documents. Thus, there is much more need of research in the area of studying the environmental impact of electric vehicle battery waste since, it is an upcoming problem area which might pose numerous implications in future.

Bibliographic coupling using clustering

Bibliometric coupling depicts the number of scientific papers which poses meaningful relation with each other. There are various categories on which bibliographic coupling can be performed such as for documents, authors, countries, sources etc. In the present study, bibliometric coupling of documents and authors is been considered for both the keyword sets (Set A and B) in scopus. There are few terms such as network, node, cluster, link strength and total link strength to understand bibliometric coupling analysis and citation analysis. Network consists of several node and a cluster is a set of closely related node. Every node in a network is assigned to exactly one cluster. VOS software uses colours to indicate the cluster to which node has been assigned. Link strength indicates the number of items cited to the selected node, whereas total link strength represents a number of times a document is cited by links strengths.

i) Documents

Figure 7 a and b shows the analysis for bibliometric coupling of documents for keywords-Set A Set B. The documents by researcher Perez-beli V is having highest number of links i.e. 653 with total link strength of 3539 and 71 citations. Premalathe m. *et al*.[5] having their document in critical review in env. Science technology, 44(14) has 584 links having 3146 of total link strength and 52 citations.

The analysis was made on VOS software by setting the search as weights: Total link strength and Scores: Citations. Bibliometric coupling of document produced by Fan E. *et al*.[6] is having 37 links having 195 as total link strength and total 9 citations till date.

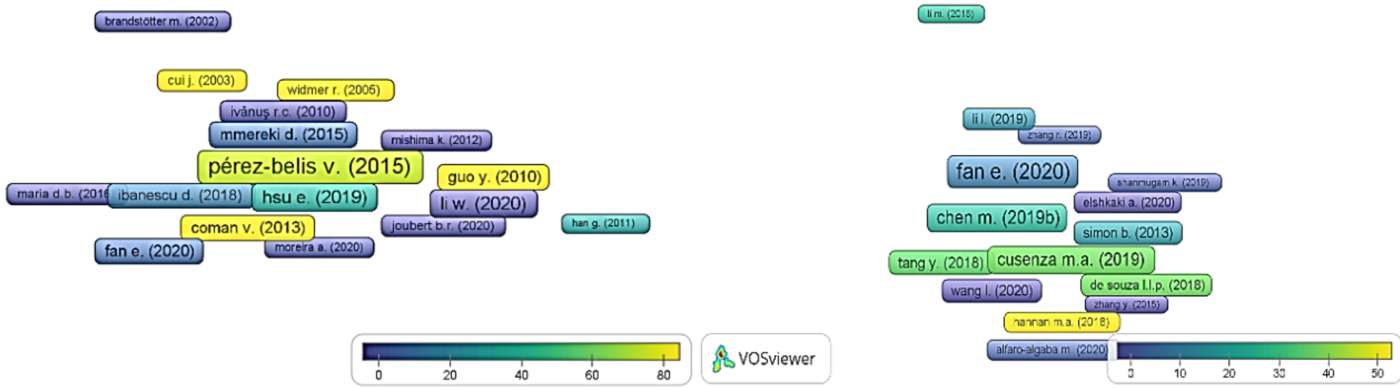

Figure 7(a) and (b): Bibliographic Coupling of documents for Set A&B.

ii) Organizations

To know various organization which are directly or indirectly inter-linked in terms of research area, keywords selection and addressing the same research problem, bibliometric coupling of organization presents fairly good idea on the same. For set A (Figure 8), there are two clusters in which organizations are closely related i.e. Cluster 1 and 2. For Cluster-1, the university having highest links and link strength is State key joint lab of environmental simulation and population control and is linked to School of Environmental Science and Engineering, Shanghai Jiao Tong Univeristy, 800 Dongchuan road and School of Environment, Tsinghua University, Beijing, China. Cluster-2 has three organization which are closely associated and University of Chinese academy of Science, Bejing, is having maximum number of links i.e. 10 with total link strength of 373, having average citation of 65.5. For set B (Figure 9), there is only one cluster formed which comprises of three organisations. Department of Mechanical Engineering, Worcester, United States has the highest number of links i.e. 3 with total link strength of 59 having average citation of 16.

Citation Analysis using clustering

Citation analysis is done to study the impact and assumed quality of an article, an author, or an institution based on the number of times works and/or authors have been cited by others. It is one of the most important parameters of a bibliometric analysis. In the present study, citation analysis is done for both the set of keywords.

Figure 8: Bibliometric coupling of organizations and corresponding documents produced for Set A.

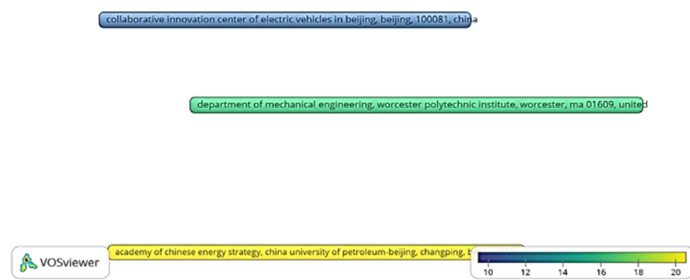

Figure 9: Bibliometric Coupling of Organization and corresponding documents for Set B.

Citation Analysis: Authors

Citation analysis using clusters is shown in Figures 10 and 11 with respect to authors. It can be seen the number of authors and citations considerably decreases for set B in comparison to set A. For set A (Figure 10), there are total 7 clusters (shown in by different colors such as red, yellow, green, purple, brown, light blue and navy blue) formed during citation analysis. Each cluster as closed group of authors and they are interlinked with authors from other clusters as well. Wong M.H from cluster 4, has 74 links with total link strength of 312, having 13 documents with 1757 citations. The second most prominent author as can be seen in Figure is Li J. from cluster 2 having 86 links which has total link strength of 634 having 52 documents and 2417 citations. Average citation of Wong M.H, which is 135, is much higher than Li. J i.e. 46.

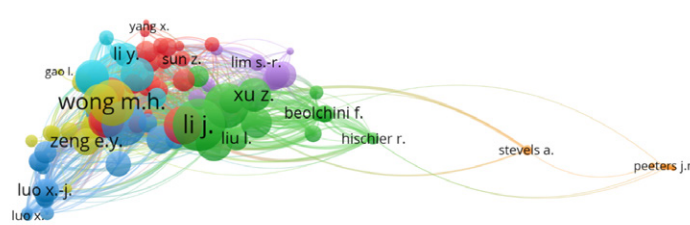

Figure 10: Network distribution for set A: Authors and corresponding citations (source: www.scopus.com).

For Set B, there are only two clusters as shown by two colors i.e. red and blue as shown in Figure 11. Li J. and Max. are in cluster 1 and Zhang Y in Cluster 2. Li. J has highest value of average citation and thus the magnitude of its icon is largest in size. The author is having 1 link with total link strength of 2, 4 documents, 215 citations and 53.75 as average citation. Zhang Y form Cluster 2 has 1 ling, 2 as Total link strength, 3 documents, 9 citations and 3 average citation value.

Figure 11: Network distribution for Set B: Author and corresponding citations. (Data source: www.scopus.com)

Citation Analysis: Sources

To know the various sources where relevant documents related to our area of interest can be identified, citation analysis for various sources is important. From Figure 12, it can be seen that for Set A, various journal names are shown which are allotted in different clusters with respect to their association with each other in the area of Environmental impact of electronic waste. Waste Management journal which lies in cluster 6 has 26 links, 397 total link strength, 91 documents, with average citation of 25 and 3407 citations. Whereas the journal having second highest citations is Environmental Science and technology which is followed by the journal; Resource Conservation and Recycling having 2502 citations.

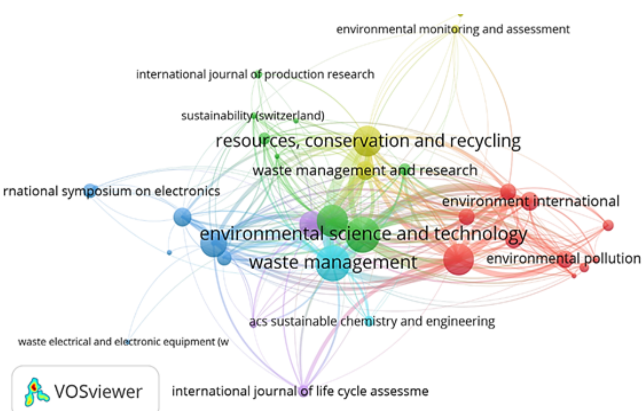

Figure 12: Citation analysis for Set A: Sources. (Data source: www.scopus.com)

For Set B (Figure 13), of 57 sources, 3 meet the thresholds and for each of 3 sources, the total strength of citation links with other sources is calculated. Three journals are: Journal of cleaner production (avg. citation of 45.56), Resource Conservation and recycling (avg. citation of 29) and SAE (avg. citation of 8) with 410, 203 and 41 citations respectively.

Citation Analysis: Countries

In order to statistically analyze, which country is contributing maximum in a particular research and to know about its link to

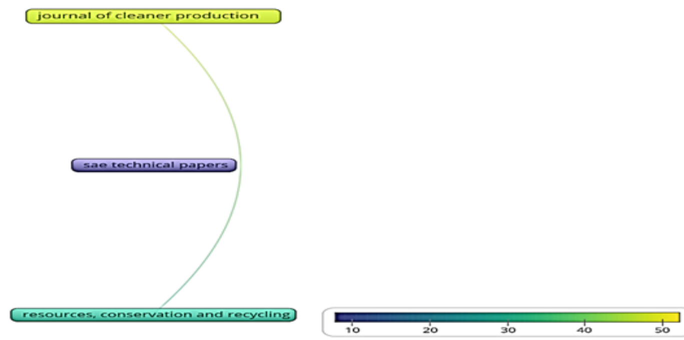

Figure 13: Citation analysis for Set B: Sources. (data source: www.scopus.com)

other countries working on the same domain can be beneficial for future research collaborations etc. For the present study on Set A (Figure 14), by considering maximum documents per country as 25 and minimum as 5, of total 119 countries, 45 met the thresholds and for each 45 countries, total strength of citation links with other countries is been calculated. There are total 10 clusters in which China comes in Cluster 5, US is also in 5 and India in 7.

From Figure 14 it can be seen that China is having highest total link strength as well as citation, followed by US and UK. China comes in cluster 5 with 44 links, 1808 total link strength, 324 documents and 10246 citations. US on the other hand comes in cluster 5 with 41 links, 1085 total link strength, 284 documents and 6349 citations. India has contributed 92 documents having 39 links over all.

For Set B, as shown in Figure 15 the network distribution is obtained by considering maximum documents per country

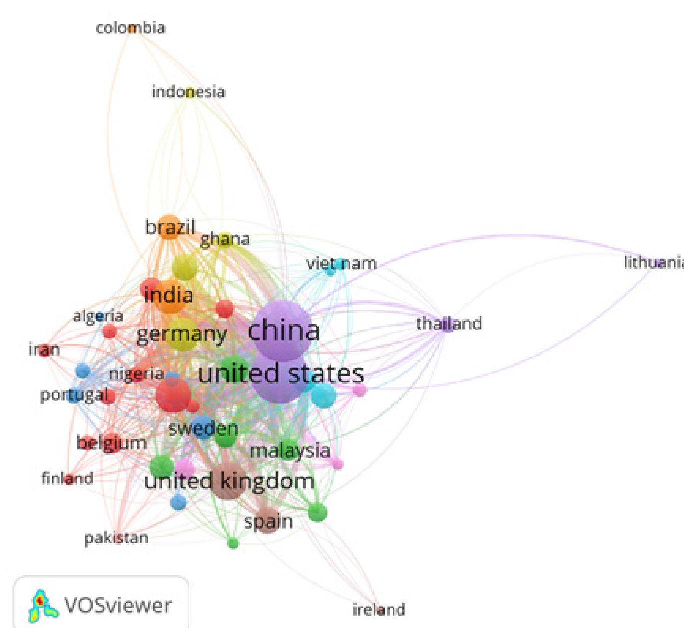

Figure 14: Network Analysis Set A: Countries. (data source: www.scopus.com)

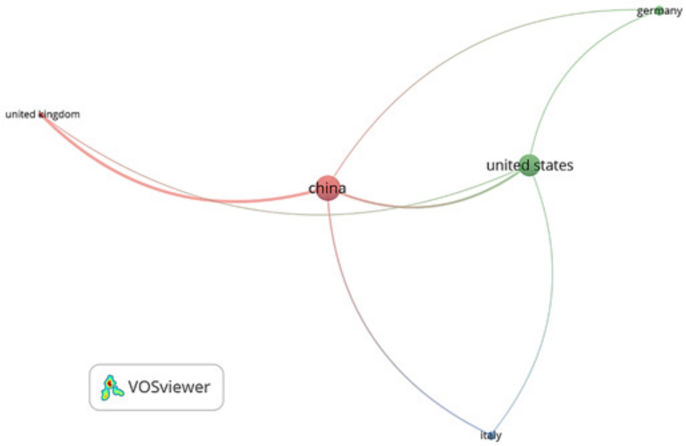

Figure 15: Citation analysis for Set B: Countries. (Data source: www.scopus.com)

as 25 and minimum as 5. Of total 25 countries, 5 met the thresholds and for each of these 5 countries, total strength of citation links with other countries is been calculated. There are only 3 clusters in which China comes in Cluster 1 with 4 links and total link strength of 13 and 449 citations. US comes in cluster 2 with 4 links, total link strength of 7 and 346 citations. Germany, UK and Italy are linked with US and China. Developing countries like India is yet to contribute in this area owing to the fact that automobile sectors are now manufacturing electric vehicles under various government schemes.

Research Implication of the Study

The increase in volume of EV has two major implication, a) Over consumption of Lithium –Ion, thus demanding end-of-life assessment b) Generation of battery waste through end –user. Hence it becomes very important to work on the solution of these two problems associated with lithium-ion batteries. This paper presents a wide range of statistics available on two giant databases: scopus and web of science. By analysing the two different set of keywords combinations (Set A and Set B), it becomes clear to the researchers, which part is still to be researched and left unexplored. The main purpose of this bibliometric survey is to produce statistical data analysis so as to reflect the level of research work already been done in this area, about the people who already have contributed and thus the researchers can accordingly decide the area in particular based on the research theme and can also connect with those who are already working in this area for better exposure. With bibliographic coupling and citation analysis, many connecting nodes becomes clear as which countries are most actively researching on electric vehicle battery waste and which are yet to start their propagation in this alarming issue of waste generation and management. Apart from this, through network analysis various authors, sources and organisations it becomes very much useful for upcoming researchers to use their experience in terms of knowledge and experience sharing or having future research collaborations which could be beneficial for the society and sustainable development. The impact of perpetual growth in e-waste and electric vehicle battery waste would ultimately affect not only the human health and environment but also the ecosystem. Few of the researchers have shown through their research how it may cause adverse impacts overall. It thus becomes important to address few geo-environmental concerns of e-waste as well as EV battery waste so as to bring awareness of this issue of concern amongst researcher, scientist and engineer's community and be able to generate solution to this problem.

Impact of E-waste and EV battery waste on human health, environment and ecosystem

Every year 20 million to 50 million metric tons of e-waste is generated as per an estimate by United Nation and only 20-25% of that are recycled formally in Asian and African countries.[7] Despite of the Basel convection, the developed nations are exporting their e-waste to developing nations.[8] Developing countries are generating secondary source of income through illegal recycling of e-waste. The e-waste due to uncontrolled landfilling and recycling has affected the overall environment adversely and the various impacts are discussed in this particular section. Table 4 shows

Table 4: Significant keyword combinations on impact of e-waste and EV battery waste. (source: www.scopus.com and www.webofknowledge.com)

Sr. No.	Keywords	Search Results	
		Scopus	Web of Science
1	Impact and of and electronic and waste and on and environment	378	250
2	Impact and of and electric and Vehicle and battery and waste and on and environment	33	18
3	Impact and of and electronic and waste and on and ecosystem	45	35
4	Impact and of and EV and battery and waste AND on and ecosystem	2	2
5	Impact and of and electronic and waste and on and soil	153	160
6	Impact and of and EV and battery and waste AND on and soil	9	4
7	Impact and of and electronic and waste and on and air and quality	20	161
8	Impact and of and EV and battery and waste and on and air and quality	7	20
9	Impact and of and electronic and waste and on human and health	256	183
10	Impact and of and EV and battery and waste and on and Human and Health	5	4

the various keyword combinations and its corresponding number of Scopus and WOS documents considering classification of impact of e-waste and EV battery waste on environment, human health and ecosystem. It can be seen from the table that the number of documents on EV battery waste is very less in comparison to number of documents on electronic waste. There are only 33 Scopus and 18 WOS documents on "Impact of EV battery waste on Environment" and 378 Scopus and 250 WOS documents are there on "Impact of Electronic waste on Environment". Similarly, the number of documents for impact on ecosystem, soil, air quality and human health is shown for electronic waste and EV battery waste, in order to draw further comparison statistically.

The recycling activities of e-waste can cause surface soil pollution by heavy metals.[9,10] In Bangalore, India few soil samples were collected from a e-waste recycling slum and the level of heavy metals crossed the regulatory threshold limit (2850 mg/kg Pb, 39 mg/kg Cd, 4.6 mg/kg In, 180 mg/kg Sb, 957 mg/kg Sn, 49 mg/kg Hg, and 2.7 mg/kg Bi) in comparison to nearby control sites of the same city.[11] The problem lies in the fact that the roots of the plants can easily absorb such harmful metals from the underlying contaminated soil and while growing these heavy metals can be transported to stem and leaf, which has chances of consumption by human or animals.[12] Thus, it has tendency to effect the whole food chain[13] analysed the impacts of heavy metals contained in e-waste on soil through experimentation and results show that it renders the soil sterile and alters its microstructure.

In many developing countries crude technology is adopted for the recycling of e-waste in which the recycling by-products are directly disposed of in the environment.[14,15] The e-waste contamination has affected the aquatic life as well. The environment wherein e-waste is disposed of is difficult for the survival of fishes and thus, such contamination is considered as a threat to wild fishes.[16] The pregnant women living near to such recycling sites are hard to barricade themselves from the exposure of heavy metals and organic pollutions, which has led to an increased possibility of premature births, reduced birth weights and infant lengths, spontaneous abortions and still births.[17,18] A study was carried out in china to know the effect of e-waste burning/ recycling on the air quality and it was found to have high mean concentrations of particulate matter (100-243.310 ± 22.729 µg/m3) and PoPs).[19]

EV battery contributes maximum to e-waste contamination and is a potential source of hazardous metal pollutants (Co, Cu, Ni, Pb) and is most likely to impact environment and human health.[2] There are different EV battery chemistries available and there is not much research available on how different types of LiBs leach under landfill condition.[20] There is a need of increased coordination of the regulatory policies in order to reduce the levels of hazardous chemical components by adopting improved recycling techniques.

Confines of the Present Study

This bibliometric survey thus brings an insight on statistics available on scopus and web of science for the environmental impact of lithium ion batteries and its end-of-life analysis. There are many bibliometric parameters considered to carry out this survey.

The following points discusses the summary of bibliometric study:

1. Set A and Set B are the combinations of keywords showing huge difference in number of documents and hence both the sets have been taken into account in both the databases.
2. The data investigation helps us to predict the growing concerns and need of the research in the particular area. We can see that for set A, there is a considerable increase in number of documents produced with time while for Set B, which is a more specific topic on end of life lithium ion battery waste the number is very less and thus, it becomes important to do research not only on environmental impact assessment of battery waste but also it needs to analysis the end-of-life of such waste flows.
3. For set A, there are 900 plus articles, nearly 200 plus review articles and 50 plus conference review in Scopus and WOS whereas for set B, its only 40 plus articles, 0 conference review in Scopus and nearly 10 review articles in Scopus and web. Likewise, the number of documents available as Editorial, Note, Data paper, book chapter, short survey is hardly one or two in both the data sets. By obtaining the statistics on subject area enables us to conclude that the research problem not only brings the researchers from engineering domain but also from material sciences, physics, chemistry, environmental sciences etc. and thus it adds to knowledge sharing from different domains.
4. Through Geographical analysis, it becomes clear that very few countries have worked on this area and only USA and China at global level have contributed in developing recycling techniques and doing the end-of-life analysis. For Set A, the number of countries involved in contribution of research document is much higher when compared to the number of countries worked on Set B. The problem of illegal recycling is predominant in developing nations and still, they are lagging behind in terms of research.
5. The statistics on author details presents us the key researchers involved majorly towards research

contribution in our topic of interest. It further helps in obtaining data about their other publications in the same area, citations, *h*-indexing etc.

6. Bibliometric coupling through clustering for documents presents an idea on authors having highest number of documents with highest links which tells the number of times the document is been bibliographically coupled with other documents. Research document by Premalathe M. *et al*. (2014) and Fan E. *et al*. (202) is having highest number of links stating highest bibliographic coupling. For Set A, the bibliometric coupling of organizations shows 2 clusters with cluster-1 having 4 organizations and cluster-2 having 3 organizations having highest links and link strength. For Set B, there is only one cluster formed comprising only 3 organization during bibliometric coupling. Thus it can be inferred that the number of organization actively involved in association in research activities for Set A is higher in number as compared to Set B and thus, the same organization can also widen their existing research area by considering the EV battery waste materials.

7. Through citation analysis, the authors having highest citation, country having maximum research document can be analyzed to generate prospects for quality research and collaboration. Wong M.H and Li J. are having highest citations and documents pertaining to Set A. Whereas for Set B, Li J again has the highest citations and next author with maximum number of citations is Max.

8. The citation analysis: sources enables us to identify journal having highest citations for Set A and Set B. Waste management, Environmental Science and technology and Resource conservation and recycling are the top three journals in terms of citations for Set A. Whereas for set B, Journal of cleaner production, resource conservation and recycling and SAE is having maximum citations. Thus, the journals identified having maximum contributions in both the data sets i.e. Set A and B can be referred by researchers to explore in this particular research theme.

9. Network Analysis in terms of citations for countries is been used to identify the countries having highest number of links and total link strength for both the set of keywords i.e. Set A and Set B. For Set A, of total 119 countries, 45 countries are at least having maximum 25 documents and minimum 5 documents. Whereas for Set B, of total 25 countries, only 5 countries are at least having maximum 25 documents and minimum 5 documents.

10. For Set A, countries like China, USA and India are having 44, 41 and 39 links respectively. Whereas for Set B, China and US are having only 4 links and UK, Italy, Germany are linked with these two nations. The citation analysis for countries thus identifies that number of countries, links, total link strength are considerably higher in number for Set A when compared to Set B. China and the USA have worked in EV batteries but there lies a huge scope in terms of research in developed as well as developing countries where the problem is more predominant.

CONCLUSION

The increase in demand of electric vehicles has resulted in increased use of lithium ion batteries. The end of life lithium ion batteries would contribute to a huge quantum of e-waste. It thus becomes very important research in the area of environmental impact of these end of life lithium ion batteries also it is important to research in the field of proper and sufficient recycling facilities for sustainable use of lithium and other metals present in end of life lithium ion batteries. The paper presents bibliometric analysis of research in the area of environmental impact of electronic waste (Set A) and Electric Vehicle battery waste (Set B). The statistics of research work done in this area till date which clearly indicates that the work done is very less in terms of research for impact of lithium ion on environment. There are only 85 research works published in Scopus till date and 28 in web of science, majorly in developed nations for environmental impact of lithium ion batteries. It is evident from the analysis of data that, in developing countries the area is almost unexplored while the problem is predominant. The analysis also revealed that there is a lot of scope for researchers to bring the solution towards end-of-life of lithium-ion battery waste as the manufacturing demand is going to increase immensely and thus, recycling will be the only solution to encourage the sustainable development. There are scientists/researchers from USA and China who are working in development of recycling techniques which states that the other counties like India, Japan, Australia which are going to witness the increase in number of electric vehicle in coming years significantly must start working towards finding the solution to this issue for the benefit of the society, environment and sustainable development.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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