REVIEW OF GLOBAL RESEARCH ON E-MOBILITY: A BIBLIOMETRIC ANALYSIS

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Resume

The present article portrays the bibliometric analysis of research conducted on E-mobility worldwide. The study aimed to understand research characteristics, evolution, challenges and potential research trends. Research articles published on E-mobility have been compiled from the Scopus database, resulting in 1737 articles published between 2001 and 2021. The software R Studio has been used for subsequent bibliometric analysis. The analysis examines the research trend in the field of E-mobility. In addition, it identifies the most productive contributors in terms of author, country and sources. Thematic analysis has been performed, as well, to reveal E-mobility research trends, including the most influential articles and authors. The study concludes that very few studies have been conducted on E-mobility and that there is much potential in E-mobility. The present paper can help the researcher pave the research path in E-mobility.

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1 Introduction

E-mobility being an emerging field, many research studies are being conducted worldwide in this field. Many pieces of research have been carried out that focus on different aspects of E-mobility. For a new researcher entering the field, the review articles provide a comprehensive overview of achievements in the field. Researchers have also published many review papers with varied objectives. For example, the review paper by Hawkins et. al. [1] discusses the environmental impact of Electric Vehicles (EVs). The article by Yong et al. [2] reviews development of the latest technologies, effects and opportunities due to EV deployment. The publication by Adnan and Nordin [3] examines EV adoption in Malaysia. Publication by Requia et al. [4] provides insights into the impact of E-mobility on GHG emissions and air pollutants. The publication by Viola [5] reviews the impact of human psychology on the adoption of EVs. Such traditional reviews adopted by many researchers help understand the cross-section of the topic and the latest facts. Still, they are not always helping researchers from developing and underdeveloped nations keep up with research publications, especially in emerging fields like E-mobility [6]. Despite the high growth rate in scientific research publications, very few attempts have analyzed worldwide publications on EVs [7]. Bibliometric studies help the researchers get insights into the global research in the field and find the research direction for future research. Bibliometric analysis is one of the most used approaches for analyzing published research [8]. The present study provides the researchers in the field with a bibliometric analysis of global research in the field of e-mobility to understand research trends and find the research gaps.

2 Literature background

Bibliometric methods are applied to analyze the output of scientific research quantitatively [9]. It uses bibliographic data from online scientific databases [10]. The number of bibliographic reviews has increased in different research areas, with increasing accessibility to bibliographic data [10]. In 2021 only, researchers like Sharifi et al. [6], Antony et al. [11], Gao et al. [12] and Sonkar et al. [13] have used bibliometric analysis for their respective research domains. The articles reported show the broad applicability of bibliometrics in different research fields.

Besides the above, bibliometric studies have also been performed in E-mobility domains. Secinaro et al. [10] have conducted a bibliometric analysis to identify a suitable business model for the EVs. Andres Barreto Ramirez et al. [14] have done bibliometric analysis for research published from 2007 to 2016. Recently, Bao et al. [15], have performed bibliometric analysis for studies on the impact of the electrification of vehicles on air quality. Hu et al. [7] have applied bibliometric analysis to evaluate research trends of EVs published from 1993 to 2012. Though attempts have been made to perform bibliometric analysis in E-mobility, the researchers have limited their scope of work by focusing on a specific domain in the field. No recent studies have focused on the bibliometric analysis of global research in the field. In addition, bibliometric information is dynamic and the reliability of the results of these studies is questionable, especially in the evolving field like E-mobility. The present study addresses the identified research gap. It provides the researchers with an overview of the research being carried out in the field of e-mobility with the help of bibliometric analysis. Four research questions (RQ), as presented below, are identified to achieve the objective of the study:

- **RQ1** - What is the scientific research trend related to E-mobility?
- **RQ2** - Who are the top contributors in research related to E-mobility in terms of authors, sources and countries over the period?
- **RQ3** - What are the thematic focus, shifts and current status of different research fields in E-mobility?
- **RQ4** - Who are the most influential contributors in terms of articles and authors?

3 Methodology

The methodology adopted for the present study is divided into various phases, as depicted in Figure 1. The study's first phase is research design, which includes formulating research questions, keyword selection, database selection etc. According to Dhamija and Bag [16], the reliability of systematic reviews like bibliometric analysis are highly dependent on selecting suitable keywords. Looking at the importance of keyword choice, authors have tried the combination of different keywords for data collection. Finally, the keywords "E-Mobility, E Mobility, Electric-Mobility and Electric Mobility" have been selected to include all the relevant research and thus maximizing the scope of the study. According to Alsharif and Baharun [17], Scopus is considered the most extensive database, with comprehensive coverage of subjects. Hence, the authors have selected the Scopus database for the present study.

The second phase of the study is data collection. It includes the loading of bibliometric data from an online database. The SCOPUS database is mined with

Figure 1 *Study Methodology*

Table 1 *Main bibliometric characteristics of the dataset*

Description	Results
Timespan	2001:2021
Sources (Journals, Books etc.)	735
Documents	1737
Average citations per document	9.701
Average citations per year per doc	1.544
References	50169
Keywords Plus (ID)	7935
Author's Keywords (DE)	3953
Authors	4566
Author Appearances	6071
Authors of single-authored documents	170
Authors of multi-authored documents	4396
Single-authored documents	248
Documents per Author	0.38
Authors per Document	2.63
Co-Authors per Documents	3.5
Collaboration Index	2.95

Table 2 *Distribution of documents*

Document Types	No. of Documents	%
Conference Paper	953	54.86
Article	626	36.04
Book Chapter	53	3.05
Review	38	2.19
Conference Review	33	1.90
Note	13	0.75
Short Survey	9	0.52
Book	6	0.35
Editorial	5	0.29
Erratum	1	0.06

the search string "TITLE-ABS-KEY ("E-Mobility" OR "Electric Mobility" OR "Electric-Mobility" OR "E Mobility")" resulting in 2,780 publications starting from 1924 to 2022. After screening, 1737 articles are included in the study.

The third phase of the study is data analysis, under which bibliometric analysis is performed on the collected data. Different software can be utilized to visualize data in the fourth phase of the study. Here, looking at the tools' abilities to meet the study's objectives, the authors have used RStudio to satisfy the need of the present study. In the final phase of the study, an interpretation of the results was made.

4 Bibliometric analysis results and discussion

4.1 Descriptive analysis

4.1.1 Dataset characteristics

1737 documents are extracted from the Scopus database, published in 735 sources from 2001 to 2021. The analyzed documents have an average citation rate of 9.701 and average citations per year per document of 1.544. The papers under the study have used a total of 50169 references. The keywords used by the authors of analyzed documents are 3953, which is more than two times the documents. At the same time, keyword plus, identified by the database, is 7935, about four times the documents and two times the authors' keywords. 4566 authors were identified, who appeared 6071 times in these documents. Of these, 170 have worked alone and the remaining 4396 have worked in collaboration. Out of 1737 documents analyzed, 248 are single-authored documents. On average, each author has published 0.38 papers and each article has 2.63 authors. In addition, the average number of co-authors per document is 3.5. The collaboration index, which is the ratio of the total number of authors of multiauthor papers to that of the total number of multiauthor documents, is 2.95 for the documents analyzed. Other characteristics of the data set are shown in Table 1.

4.1.2 Distribution of document types

The documents analyzed by the present study comprised 11 document types. The most frequently used document type is conference paper (953), accounting for 54.86% of scientific production. This is similar to Hu et al. [7], with 59.57% of total production as conference papers. The conference papers are followed by Article (626), which accounts for 36.04% of total scientific production. Conference papers and articles combined account for over 90% of total production. The distribution of the document is shown in Table 2.

4.1.3 Annual production of research

The present study analyzed scientific production from 2001 to 2021. The annual scientific production in E-mobility is depicted in Figure 2. The research in E-mobility had a slow growth from 2001 to 2008, with just 20 publications accounting for just 1.15% of total production. The remaining period (2009-2021) shows a constant growth in scientific output. In addition, most publications (98.84%) are from this period. Overall research production has shown an Annual Growth Rate (AGR) of 31.77%. Compared to the average science growth rate given by Bornmann and Mutz [18], which is around 8 – 9% per year, the growth rate for research in E-mobility is much higher. This growth indicates the interest of researchers in various sectors related to EVs, with the introduction of EVs in multiple markets.

4.1.4 Top Contributors

4.1.4.1 Authors

As discussed earlier, 4566 authors responsible for 1737 articles were identified, from which the authors having the highest number of publications are discussed in this section. Benjamin K. Sovacool is the most contributing author, with 29 articles published from 2016 to 2021. Johannes Kester and Lance Noel follow

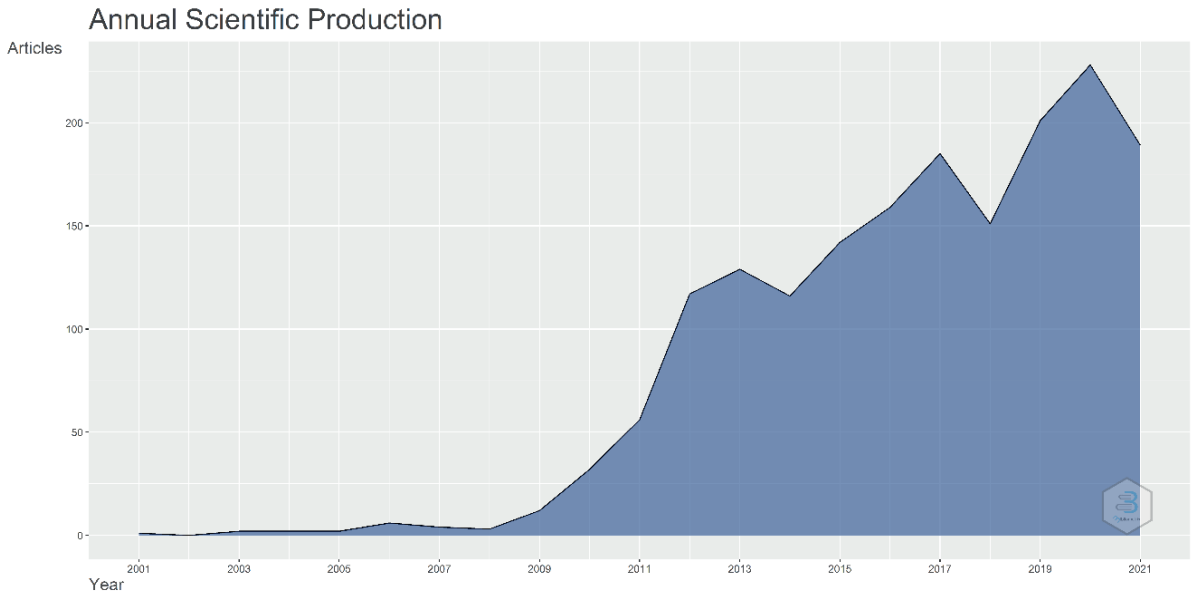

Figure 2 *Annual Scientific Production*

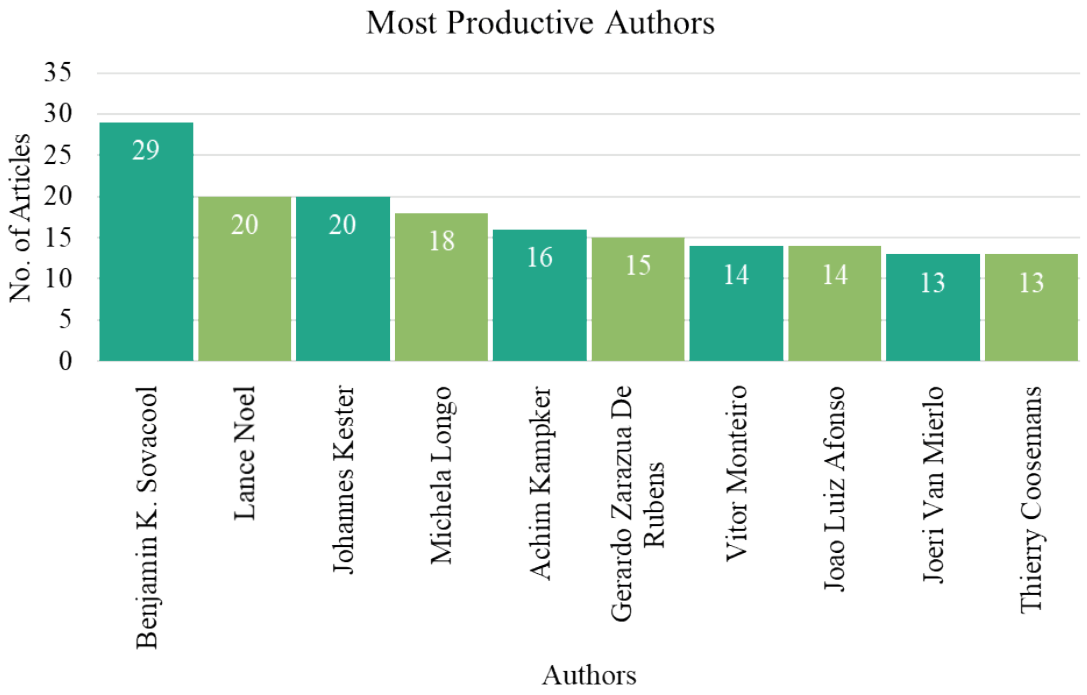

Figure 3 *Most productive authors*

Benjamin K. Sovacool with 20 publications each. Figure 3 shows the top 10 authors with the highest number of documents published during the period under consideration.

Of the top ten authors, Achim Kampker, Joao Luiz Afonso and Vitor Monteiro have the highest experience of 10 years each. Though some authors have heavily contributed to the field of E-mobility, there is no proof of productive elites. The above inference can be backed by the observation that 3,789 authors, which account for around 83 % of all authors, have published only a single article. The possible explanation for this may be the interest of young researchers in the field. These results also indicate that research in E-mobility has interest from many researchers, characterizing it as a topic in trend.

4.1.4.2 Sources

As discussed earlier, 735 sources responsible for publishing 1,737 articles were identified, from which the sources with the highest number of publications are discussed in this section. Table 3 shows the top ten sources publishing the highest number of documents. As per the table, EVS 2017 has the highest number of publications (51). From the category of journals, WEVJ has the highest number of publications (49) having the

Table 3 *Top 10 sources publishing research on E-mobility*

Sources	Articles
EVS 2017 - 30th International Electric Vehicle Symposium and Exhibition	51
World Electric Vehicle Journal (WEVJ)	49
Sustainability (Switzerland)	36
Transportation Research Procedia	35
VDI Berichte	33
SAE Technical Papers	30
Procedia CIRP	28
Applied Energy	26
EVS 2016 - 29th International Electric Vehicle Symposium	23
Automotive Industries AI	23

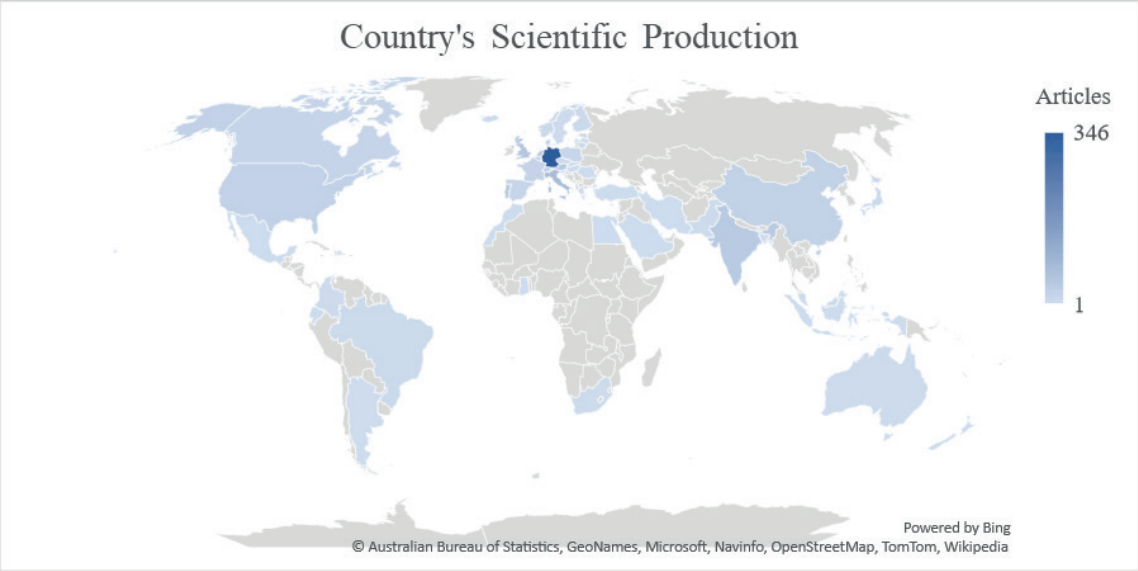

Figure 4 *Country's Scientific Production*

keyword E-mobility. The distribution of articles can explain the presence of conferences in the list of top contributing sources discussed earlier, which indicated conference papers account for 54.86% of total articles.

The authors have also carried out Bradford's Dispersion Law Analysis [19]. Bradford's law describes how the research is dispersed throughout the scientific publishing sources. In Bradford's Dispersion Law Analysis, sources of articles are first arranged in decreasing order according to the number of articles per source. Then the articles are divided into three distinct zones, such that each zone contains approximately 1/3rd of the total articles. According to this analysis, zone 1, which shows the most productive sources, has 27 sources with 577 publications. Zone 2, which includes many less productive sources, contains 167 sources responsible for 587 articles. At last, zone 3, which depicts more sources with lesser publications, has 541 sources with 573 publications. Hence, out of 735 sources responsible for publications in E-mobility, only 27 sources, which account for just 3.4% of all the sources, were responsible for approximately 1/3rd of publications.

4.1.4.3 Countries

From the documents analyzed, 70 countries have been identified as having scientific contributions to E-mobility. Figure 4 shows the countries according to their scientific production. According to the country of the corresponding author, Germany has the highest, i.e., 346 articles. This can be explained by Germany being considered an automobile hub, responsible for new developments in the automotive industry. Germany is followed by Italy, the UK, India and Austria, with 71, 49, 43, 43 and 40 articles in the top five. This shows that the European countries have more dominance in publishing research articles in E-mobility research.

4.1.5 Most influential contributors

4.1.5.1 Documents

21 articles have received more than 100 global citations and 569 have received zero citations. Out

Table 4 *Top 20 authors with the highest citations*

Authors (Global citation)	TC	Authors (Global citation)	TC
Benjamin K. Sovacool	724	Sungu Hwang	542
Simone Abram	619	Ji-Eun Jeong	542
Merlinda Andoni	619	Jinyoung Kim	542
David Flynn	619	Seo-jin Ko	542
Dale Geach	619	Thanh Laun Nguyen	542
David Jenkins	619	Tae Joo Shin	542
Peter McCallum	619	Mohammad Afsar Uddin	542
Andrew Peacock	619	Bright Walker	542
Valentin Robu	619	Han Young Woo	542
Hyosung Choi	542	Seungjib Yum	542

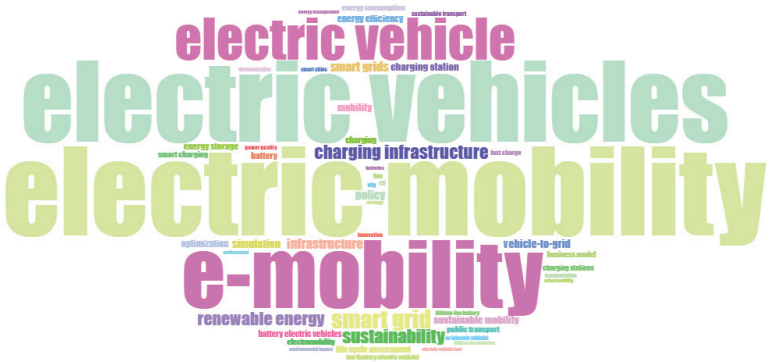

Figure 5 *Word cloud - Author's keywords*

of these 569 articles, 107, accounting for 18.80% of articles with zero citations, were only published in 2021. This can be the possible explanation for fewer citations. The most influential research is by Andoni et al. [20], with 619 citations. This study identifies challenges and opportunities to blockchain technology for various sectors, including E-mobility. Based on local citations, the most influential document is by Dijk et al. [21], with 38 local and 198 global citations. This paper reviews EV's development before and after 2005, focusing on factors responsible for the shift to E-mobility and factors acting as barriers towards the further growth. The second most influential document, based on local citations, is by Franke et al. [22], with 20 and 243 local and global citations, respectively, focusing on understanding psychological barriers in E-mobility adaptation. Next is by Sovacool [23], with 17 local and 61 global citations. According to the bibliometric analysis of the present study, the author is the most productive in E-mobility. In this paper, the author integrates the theory of mobility with actor-network theory and a unified theory of acceptance and the use of technology and proposes a framework for E-mobility adoption.

4.1.5.2 Authors

This section identifies the most influential authors based on the number of global citations. A total of 4566 authors responsible for publishing 1737 articles have been identified in the study. Only 116 authors, accounting for 2.54% of the total, have received more than 100 citations. The author Benjamin K. Sovacool has received the highest number of citations (724) for his work. 1255 authors out of 4566, accounting for 27.5%, have received no citation. This again proves the non-existence of a productive elite. Table 4 shows the top 20 most influential authors in E-mobility. It can be seen that except for Benjamin K. Sovacool, all other authors having the highest citations are responsible for two articles, Andoni et al. [20] and Nguyen et al. [24]. Hence, they cannot be considered the most influential authors of E-mobility.

4.2 Thematic trend analysis

4.2.1 Most frequent keywords

1737 documents analyzed in the present study identified 3,953 authors' keywords. The top ten most frequently used Authors' keywords include "electric mobility (256)", "electric vehicles (234)", "e-mobility (196)", "electric vehicle (121)", "smart grid (53)", "charging infrastructure (41)", "sustainability (41)", "renewable energy (39)", "infrastructure (30)" and "smart grids (28)". It can be observed that authors use a variety of keywords indicating the same ideas

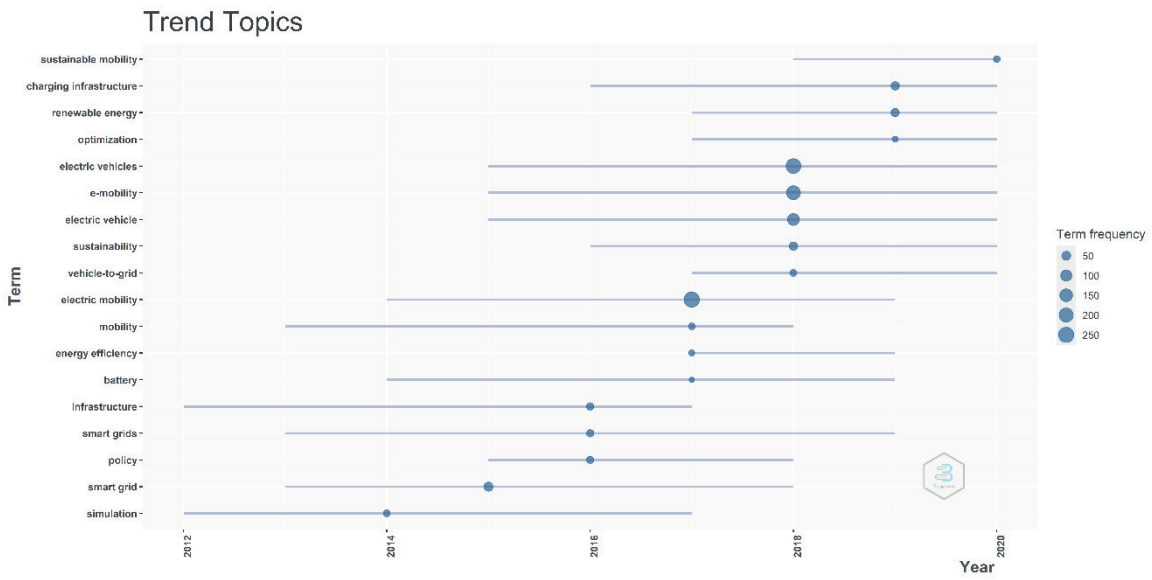

Figure 6 *Trend topics*

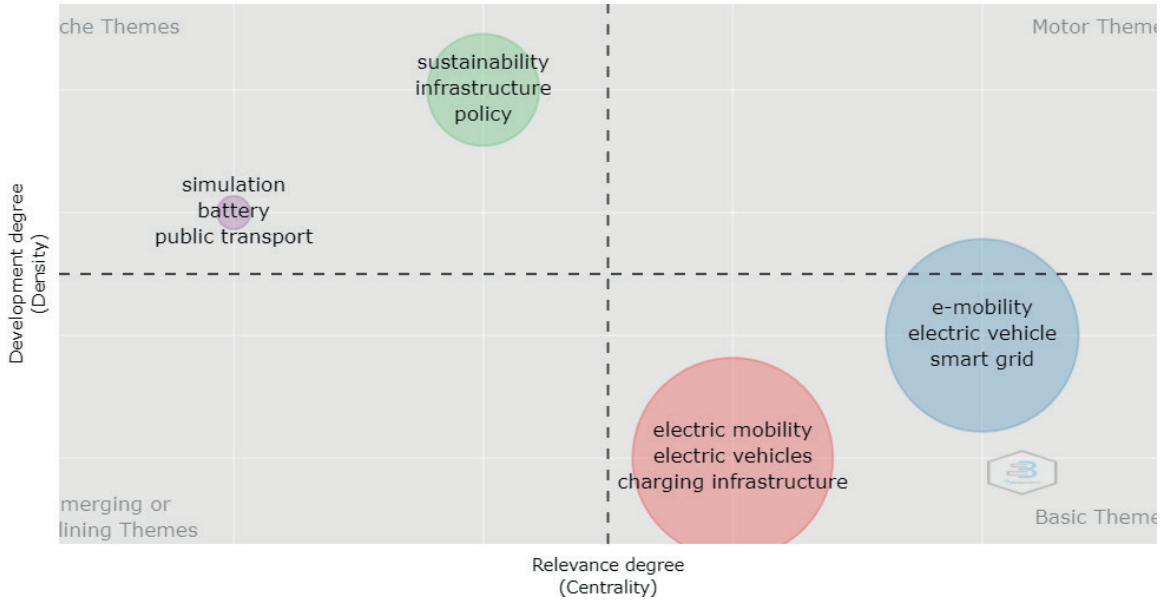

Figure 7 *Thematic Map*

with slight variations. In addition, the same word is sometimes used in singular or plural forms by different researchers. For example, "Electric Vehicles," "Electric Vehicle," "EV," and "EVs," etc. This presents the authors with the challenge of drawing scientific inferences from the results. Figure 5 shows the word cloud for authors' keywords, showing the top 50 words, with frequency as a word occurrence measure. A word cloud is a diagram showing frequently used words in which the size of the word represents the frequency.

4.2.2 Trend topics

Figure 6 shows the trend topic analysis based on authors' keywords, with parameters for minimum frequency as 20 and the number of words per year as 5. The plot generated shows 18 keywords with their research trends. According to Figure 6, the topic of interest for researchers during the period 2014-2016 included keywords like smart grid, policy etc. During the period 2016-2018, the interest of the researchers shifted towards energy efficiency. After 2018, the topic of interest for the researchers shifted towards the sustainable mobility, charging infrastructure, renewable energy etc. From the above observation, it can be inferred that E-mobility is a continuously evolving field. The focus of researchers has shifted to sustainable mobility and renewable energy in the present times. This also reflects the increasing awareness of sustainability in the community.

4.2.3 Thematic map

Figure 7 shows the thematic map generated with parameters, number of words as 90, minimum cluster frequency per thousand documents as 5 and number of labels for each cluster as 3, on authors' keywords identified from the extracted database. The thematic map divides the research into four themes: emerging or declining themes, basic themes, motor themes and niche themes based on development degree and relevance degree. Figure 7 shows that research related to the blue cluster has very high relevance and medium development, including keywords such as electric vehicle, smart grid etc. Cluster red, which includes the keywords charging infrastructure, optimization etc., has high relevancy and low development. Next, clusters green and purple are under niche themes with high to very high development and low to medium relevance. These clusters include keywords like policy, climate change, public transport etc.

From the above observation, it can be inferred that though the cluster red has high relevance, development is very low. Hence, the researchers may focus more on that cluster. Cluster blue, the cluster having the highest relevance and moving towards high development, indicates that the cluster will transfer from a basic theme to a motor theme in due time. The clusters green and purple, suggesting niche themes, show the areas connected with E-mobility with lower relevance but comparatively higher development.

4.2.4 Potential research trends

Based on the above discussions, the authors have identified potential research topics. According to the authors, research areas like vehicle, battery and charging technology have been researched intensively in the past few years. Hence, it can be said that these areas have been developed to a satisfactory level. Presently, researchers focus on challenges of mass adoption, policies, mass diffusion of technology etc. According to the authors, the potential research areas for future researchers can be optimization of range, charging infrastructure planning and related services, making EVs affordable for mass adoption, battery recycling, smart grid etc.

5 Conclusion

The study analyzed bibliometric information from 1737 pieces of research published in 735 sources from 2001 to 2021. A total of 4566 authors from 70 countries have contributed to these researches. Research in the field gained momentum after 2009. Overall, publications have shown an AGR of 31.77 %, making it a topic of interest for research. The publications are distributed among 11 document types, among which conference papers account for more than half of total production. Conference papers are followed by journal articles combinedly, accounting for more than 90 % of scientific production.

According to the analysis, Benjamin K. Sovacool is the most contributing author, with 29 articles published between 2016 and 2021. In terms of time, Achim Kampker, Joao Luiz Afonso and Vitor Monteiro have contributed for ten years in the field. Out of 4566 authors identified, 3789 authors have published a single article. Hence non-existence of productive elites has been observed in the field. For sources publishing research related to E-mobility, EVS 2017 has the highest number of articles published, followed by the World Electric Vehicle Journal. In addition, Bradford's [19] dispersion law identified the top 27 sources responsible for approximately 1/3rd of articles. According to the analysis, Germany is the most productive country, responsible for 346 publications. A clear dominance of European countries has been observed in research in the field.

The results of the thematic analysis state that out of 3935 keywords mentioned by authors, "Electric Mobility," "Electric Vehicles," "E-mobility," and "Electric Vehicle" are highly frequent. According to trend topic analysis, the current topic of interest includes "Sustainable Mobility," "Charging Infrastructure," "Renewable Energy," etc. According to the thematic map, publications with keywords like "Electric Vehicle," "Smart Grid," etc., are identified as highly relevant and relatively more developed. In comparison, publications with keywords "Charging Infrastructure," "Optimization," etc., are identified as highly relevant but relatively less developed.

The articles by Andoni et al. [20], Nguyen et al. [24] and Peters et al. [25] are among the most influential articles based on global citation. Based on the local citation, the most influential papers include Dijk et al. [21], Franke and Krems [26] and Sovacool [23]. The most influential and top contributing author is Benjamin K. Sovacool.

According to the authors, as vehicle technology has been developed satisfactorily, it can be a topic of declining interest. Topics like charging infrastructure and smart grids are expected to stay in trend for a few years. Battery technology can also be expected to remain in trend due to the need for an alternative to what is presently available because of its environmental impact. In the future, topics related to business models for charging infrastructure, battery swapping technology, flash charging, wireless charging etc., are expected to stay in focus. Other than these, research focused on optimizing technology to make it more affordable is expected to remain on-trend.

6 Limitations and future scope of the study

The first potential limitation is that the bibliographic information is dynamic and is expected to change with time. Hence, the study can be revised after further growth to incorporate future developments. Despite Scopus being a comprehensive database, journals are indexed in various databases or non-indexed. Research published in such journals may have been lost. More accurate results can be obtained by including such journals in future studies. In addition, authors may use different initials, multiple names, or different names in various publications. This limitation can cause a slight deviation in the results of bibliometric analysis.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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