International Journal of Transport Development and Integration
Vol. 8, No. 2, June, 2024, pp. 301-314
Journal homepage: http://iieta.org/journals/ijtdi

Exploring EV Charging Time Optimization: A Bibliometric Analysis

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https://doi.org/10.18280/ijtdi.080208

Received: 7 April 2024
Revised: 2 June 2024
Accepted: 11 June 2024
Available online: 30 June 2024

Keywords:
bibliometric analysis, electric vehicle (EV), charging time, battery models, sustainable transportation, charging infrastructure, urban studies

ABSTRACT

Rapid growth in the global electric vehicle (EV) market has sparked extensive research, with charging time remaining a critical concern. This study presents a descriptive analysis of research publications on EV charging time from 2017 to April 2024, highlighting trends, characteristics, and global perspectives and identifying research gaps. Scopus, an extensively utilized and frequently cited bibliographic database among the global research community, served as the primary data source for this investigation. Based on the Scopus database, the analysis reveals a growing interest in optimizing charging times, with notable peaks and troughs in publication trends. Interdisciplinary collaboration is evident, with engineering, computer science, and energy research leading the field. Key thematic clusters focus on charging infrastructure, battery optimization, and integration with renewable energy sources. Research gaps and emerging areas include fast-charging technology, battery management systems, and grid integration. A future research roadmap suggests investigating fundamental charging mechanisms, developing intelligent charging systems, exploring socio-economic implications, and fostering international collaborations. While progress has been made, further research is needed to address challenges and drive innovation in EV charging technology for sustainable transportation solutions.

1. INTRODUCTION

The rapid growth of the global electric vehicle (EV) market has spurred extensive research. Yet, Sun et al. [1] show that the charging time issue remains a critical concern, prompting the need for simplified battery models applicable to system-level analyses. Shi et al. [2] also show that in combating climate change drives the increasing popularity of electric vehicles. However, the lengthy charging time remains a significant issue that needs addressing [2]. This success story cited in the study [3] demonstrates that there is promise for incorporating aggregated EVs into secondary frequency regulation in renewable energy-weighted grids. However, consistent availability of the secondary frequency regulation (SFR) capacities and provision of supporting post-automatic generation control (AGC) signals are still problematic. The issues make worse by worries over the time taken to recharge, which may also increase because of provision in SFR [3].

The spread of electric vehicles (EVs) gave an impetus to work on infrastructure capable of reducing the charging time, and here is where research related to it went. Therefore, comprehending the patterns made by the entire earth regarding one of the aid of sustainable transportation - the reduced EV charge time - is critical.

The time spent to charge EVs is a major factor that will affect the market penetration of an EV device [4]. Long charging times could turn off potential buyers, while a short charging time can make the EV more appealing and give it the edge in this very competitive segment. There can be various impacts of the charging time on the usability of an EV, affecting travel planning, overall efficiency and user satisfaction especially in context of electric vehicles.

Charge time is one of the most significant barriers to the widespread adoption of EVs - if this can be optimised, range anxiety among users could be substantially reduced. But, of course faster charging rates present complex technical and logistical challenges to maintain battery health and grid stability.

But this evolution in the research landscape of EV charging time need to be understood systematically and holistically. From this perspective, the bibliometric analysis is a methodological tool for providing qualitative and quantitative insights, to create a panorama of trends, characteristics and global perspectives in research publications on EV charging time [5]. By contrast, there are undeniable strengths of bibliometric analysis compared with alternative types of review such as systematic reviews and meta-analyses. In contrast to systematic reviews that synthesize the current literature to answer particular research questions, bibliometric analysis provides a more distant view of publication patterns, citation networks and collaboration trends within a given field of research [6]. This broad view is well-suited in consideration

of EV charging, where development of relevant technologies, governmental actions and consumer preferences effect the preferences for research directions and end results [7].

In addition, this study employs bibliometric analysis as the rationale of selecting this method is its deep assessment to explore unobvious patterns and evitable trends within the large number of diverse literature on EV charging time. Systematic bibliometric analysis of publication metadata such as author affiliations, citation networks, and keyword co-occurrences have the potential to reveal relationships in the research landscape which inform strategic decision-makers and guide future efforts.

Technological innovation and market dynamics are constantly changing, which makes EV charging particularly relevant for bibliometric analysis, as this allows trends to be monitored in a timely manner (at low costs) and knowledge gaps to be identified. Disclosing the knowledge structure of a field, and identifying main research themes and new-emerging subfields, allows researchers, policymakers, and industry to take well-informed,wisely-directed actions.

There are still essential research areas that did not get an appropriate level of focus in the literature - fast charging technology, battery management systems (BMS) for aging-reduced operation along with renewables integration, grid-based charging & optimal framing and developments in battery materials and technologies.

This type of analysis is a form of bibliometrics, which represents an important and trusted means to systematically interpret vast scientific datasets. It makes it possible to follow the development of interest in a specific area and, on the other hand, highlights new research trends and hot subfields [8]. In fact, Bibliometric analysis serves fund manager a lot like it helps in tracking article and journal performance trends, reviewing collaboration patterns and research stakeholders, and more importantly, analyzing the intellectual structure of the literature within a specific domain [9].

The study seeks to present the descriptive analysis of the literature about EV charging time, expose research trends, characteristics and global perspectives as well as thematic areas, research gaps and a future research roadmap for meeting upcoming challenges and opportunities in this area. The Scopus dataset, one of the largest and most coherent bibliographical repositories, is to be used as data source in this study.

2. METHODOLOGY

In this study, a bibliometric analysis is taken to investigate the global research fronts for charging time of electric vehicle (EV) batteries. The step-by-step methodology includes:

2.1 Data collection

We used the Scopus database as our primary data source for this analysis as it is an established and wide-ranging bibliometric resource that covers most peer-reviewed literature in diverse fields. A systematic search was undertaken with relevant keywords such as “Charging Time” and “Electric Vehicle” only in the title of an article. The search was restricted to works published from 2017 until April 2024, including studies that delivered new subjects in the literature.

Enter the keywords in the search box of Scopus ington by email to request the data, visit nature. com, go to "analyze results" and click on the figure or chart for the number of documents (the tables appear in order of number of documents by year, type, subject area, source, author affiliation, country and funding sponsor). These values are later evaluated in the outcomes. On the other hand, the CSV files are further downloaded/exported and finally, they are made through VOSviewer available for qualitative bibliometric network visualization, overlays, and density.

2.2 Document selection

Following the first search, further review and eligibility assessment of these documents was conducted based on the research questions [10]. Peer-reviewed journal articles, conference papers and book chapters on the optimization of EV charging time, infrastructure, the battery management system, etc. were placed in the inclusion scope.

Documents were included in the review if clear criteria identified the content related to one of the main themes as perceived by the authors and if the document was academically credible [11]. Articles that were included here had first of all been highly scrutinized and were peer-reviewed subjects such as the EV charging time optimization, infrastructure, safety, battery management systems and other related topics. These criteria were developed in an effort to identify legitimate research articles that significantly contributed to the field and had been rigorously reviewed by other academics [12].

Exclusion criteria were strictly applied to documents found on Scopus so as to not compromise the fidelity and validity of the analysis. All will be included for screening, but excluded for review and synthesis if the document is not English based on qualitative analysis expertise. We used these inclusion and exclusion criteria to enhance the relevance, quality and comprehensiveness of the dataset applied for bibliometric evaluation [13]. The study attempted to reduce potential biases and enhance the validity of the findings by adhering to strict criteria.

2.3 Data analysis

Analysis of the selected documents identified potential trends, characteristics and thematic clusters in the research landscape [14]. Bibliometric evaluation is the detected quantitative metrics (e.g. publication counts, types, and years) trends over time [15]. We also conducted a qualitative analysis to seek thematic clusters and emergent topics of interest.

2.4 Visualization

Results were visualized with network plots, overlay plots, density plots using VOSviewer software [16]. They help to identify thematic clusters, key contributors and global research trends [17].

VOSviewer, which is a popular bibliometric analysis tool for visualizing bibliographic data and the exploration of research landscapes. Keyword co-occurrence analysis is one of the techniques used to find patterns, clusters and relationships in huge academical publication dataset. Moreover, VOSviewer provides tools for network visualizations, overlay visualizations and density visualization which are helpful to identify thematic clusters, key contributors and global research trends [18]. Additionally, VOSviewer offers statistical tools (including clustering

algorithms and multidimensional scaling) which allow to analyze the downloaded bibliometric data.

2.5 Future research roadmap

A future research roadmap was developed using the identified research gaps and emerging areas. In this discussion, we highlight potential directions for future research, focusing on the need for interdisciplinary research, international collaboration and socio-economic implications of EV charging time optimization.

This study hopes to help promote the development of research in this crucial area of sustainable transportation by offering a systemic method for data collection, analysis and interpretation that should provide a holistic account of current landscape in electric vehicle battery charging time research.

2.6 Stages of bibliometric analysis

The stages of the bibliometric analysis of this study are in Figure 1.

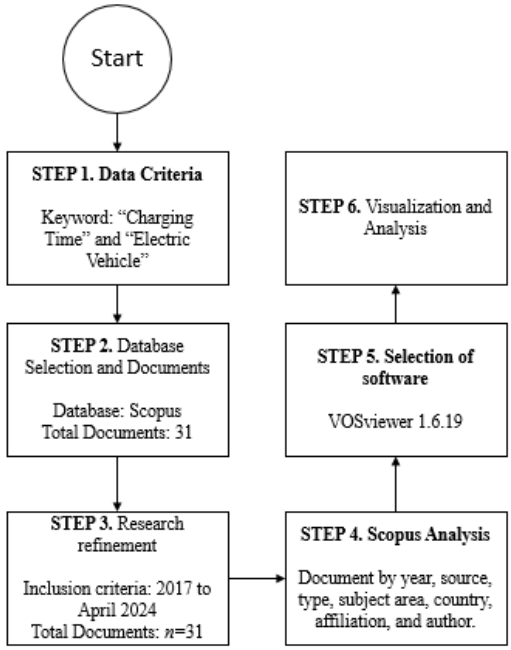

Figure 1. Stages of bibliometric analysis

3. RESULT

The present work presents a bibliometric analysis of the papers in related fields "Charging Time" and "Electric Vehicles" on Scopus database between 2017 and April 2024. We reviewed 31 documents in total. The findings provide insights on how research interest in this field has evolved and patterns with a general increase in publications along with notable peaks and troughs.

3.1 Exploring trends and characteristics of publications on "charging time of the electric vehicle battery"

The rapid evolution of electric vehicles (EVs) has made the improvement of charging infrastructure an obvious requirement, especially in relation to decreasing the time taken to charge. Figure 2 illustrates the publication trend of "Charging Time" and "Electric Vehicles" from Year of 2017 to April 2024, which is helpful for us to perceive the research evolution in this area. The data was obtained from Scopus database, a well-known source of peer-reviewed literature.

The search was each made with "Electronic Vehicles" and "Charging Time" as a title in the Scopus database. The search covered materials published from 2017 to April 2024. Thirty-one papers were included in this review. This analysis included counting the publications for each year and focusing on trends as well as exceptions.

Based on the analysis performed, publications related to "Charging Time" and "Electronic Vehicles" began in 2017 with an original count of two publications. Based on this, it can be inferred that research interest in the very technology of EV was building during this time as well. The figure, number of publications, shows that by 2018 there were six papers published so it is possible the message around the need to reduce charging time for passenger EV adoption was beginning to get through.

But in 2019 there was a distinctive pull back, with as few as two outputs agreed in the end to match the early 20 of 2017. This downward trend could represent temporary aspects of research in question or funding layout. Next years 2020 and 2021 continued with 2 publications each. The stagnation aspect of this period may be indicative of research advances and delays in publication.

There was a small increase in 2022 with four publications. That upward trend stayed strong at a huge 9 publications in 2023. The jump could similarly indicate that more research and technology has been focused on overcoming the problem of charge times, maybe in preparation for wider EV adoption and initiatives to spur EV infrastructure in 2023.

There are two publications from as of April 2024, and of the partial status of years data it is very likely that more will publish late 2024. The continued research progress for this week reflects the sustained importance of and momentum in R&D to reduce EV charging times - demonstrating that researchers worldwide are looking for new, innovative approaches to addressing those downstream challenges and bolstering global clean transportation progress on the right towards sustainable mobility. These fluctuations in publication trends over the years reflect matching broader technological and societal developments and changes in consumer preferences, the regulatory framework, and investment patterns in clean energy technologies. These have an impact on the research priorities and allocations of funding; and hence the path of EV charging infrastructure optimisation research. Consequently, a more detailed examination of the publication developments within higher technology and societal drivers is paramount in allowing the evaluation of the changing EV charging research territory and its impacts on sustainable transport.

The distribution of publications on the charging time of EV batteries by academic disciplines is shown in Figure 3. The study shows this is a very interdisciplinary research area with considerable input from various areas.

The research that most contributes to research on EV battery charging times is led by Engineering at 26.4%. That's not surprising, since it is a technically complex problem to solve through better battery design, changes to charging infrastructure, and development of new materials. While the above areas can help create an ideal ubiquitous charging network, engineers work at a ground-level best to offer

practical solutions and technological advancements which directly affect efficiency & effectiveness of EV charging systems.

In second place, you can see the field of Computer Science with 22.2%. The impact statement of this field demonstrates the continuously increasing significance of computational methods and algorithms for scheduling charging processes as well as controlling energy systems based on intelligent grid technologies.

Energy research comes in third (16.7%) underlining how important it is to look at the wider consequences of EV charging on energy systems. Academic Partners for this area are more focused on (Not only limited to): Sustainable energy sources, grid integration and environmental consequences of EVs. This synergy of the study on energy related to EV technology emphasizes the move towards more sustainable alternatives.

15.3% also involves mathematics, recognizing that mathematical modeling of problems and optimization can be very relevant to EV charging complex issues. There, mathematical methodologies help to construct algorithms which on one hand increase the efficiency of charging and decrease costs, while on the other side provide extended lifetime for stage 2 batteries.

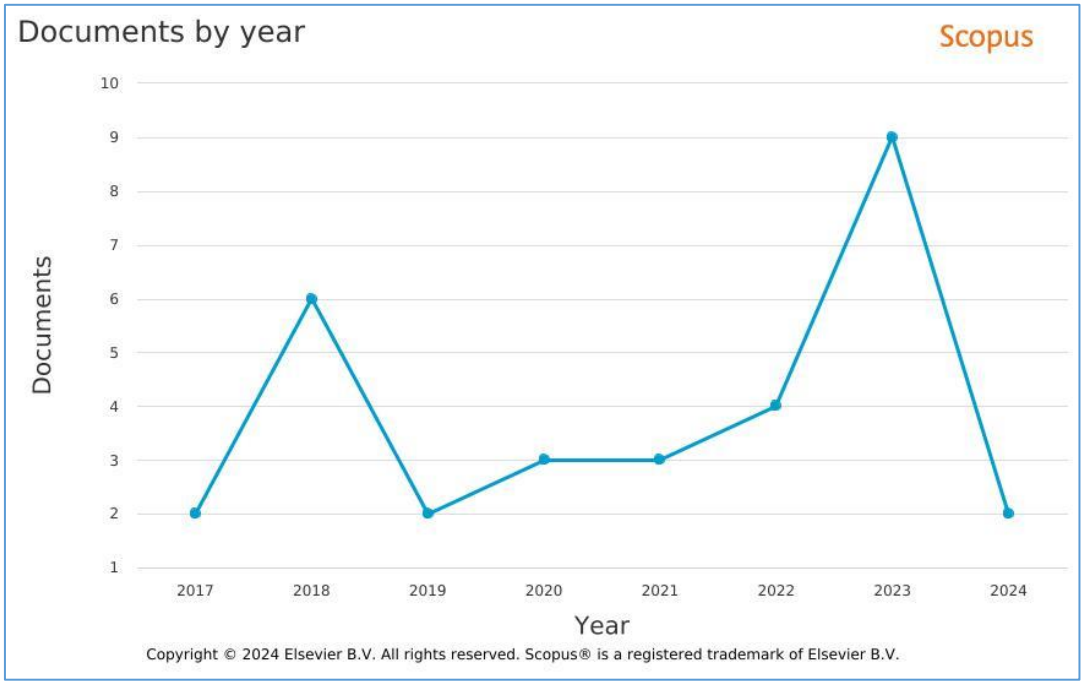

Figure 2. Publication trends by year
Source: Scopus database on April 2024

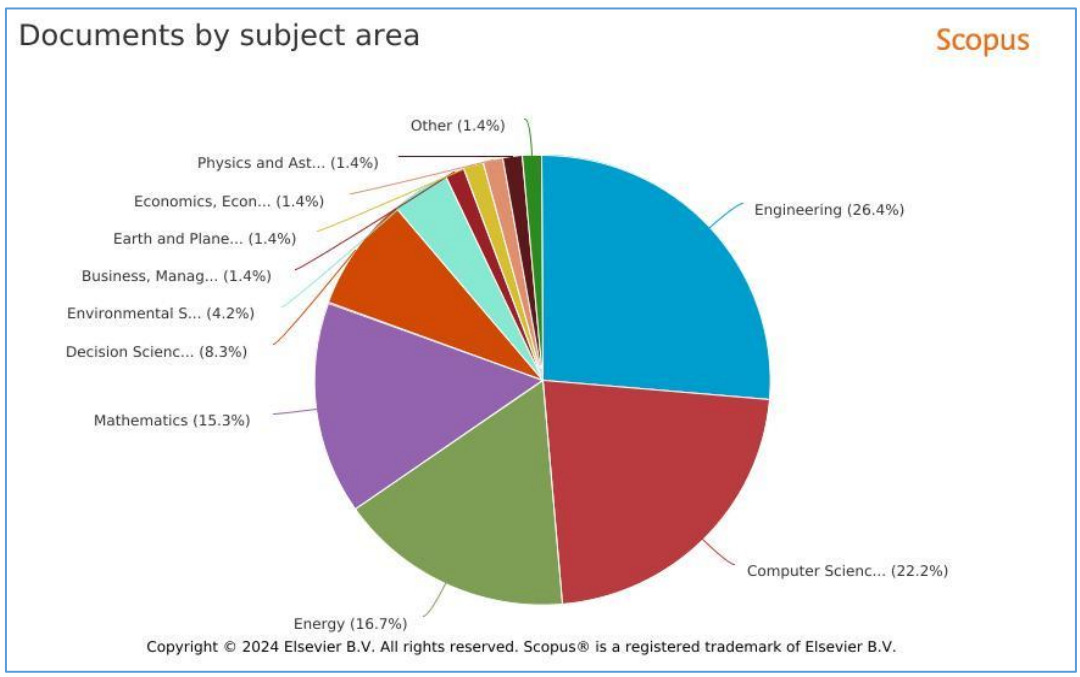

Figure 3. Publication by subject area
Source: Scopus database on April 2024

The remaining publications are distributed across various fields, including Decision Sciences, Environmental Science, Business, Management and Accounting, Earth and Planetary Sciences, Economics, Econometrics and Finance, Physics and Astronomy, and Social Sciences. These contributions highlight the multifaceted nature of EV charging time research. Decision Sciences and Business, Management, and Accounting examine the economic and managerial aspects of EV deployment and charging infrastructure. Environmental Science focuses on the ecological impact, while Physics and Astronomy contribute to the fundamentals.

The bibliometric analysis reveals that research on the charging time of EV batteries is highly interdisciplinary, with significant contributions from Engineering, Computer Science, and Energy. This diversity reflects the multifaceted challenges involved in optimizing EV charging times and underscores the need for collaborative efforts across different fields to address these challenges effectively. As the EV market grows, further interdisciplinary research will be essential to develop innovative solutions for faster, more efficient, and sustainable EV charging.

Figure 4 revealed three primary publication formats for research on EV battery charging times: peer-reviewed journal articles, conference papers, and book chapters.

Firstly, *Peer-Reviewed Journal Articles (54.8%)*. The majority of EV battery charging time is peer-reviewed material. And this preference highlights the prestige of journals and peer review as well as the intellectual assurance that journal publications provide. These journals are generally peer reviewed to ensure scientific accuracy, novelty and importance. It is a common platform that has an extensive coverage and outreach in the academic field. It allows researchers to add to the body of literature and build upon it with in-depth, well-supported studies

Secondly, conference papers represent the second most utilized platform, accounting for 41.9% of the publications. Conferences are essential venues for the dissemination of cutting-edge research and immediate findings. They provide a dynamic forum for researchers to present their work, receive feedback, and discuss with peers. The relatively high proportion of conference papers indicates the fast-paced nature of EV battery charging technologies research, where timely sharing of results and ongoing developments is crucial. Conferences also offer networking opportunities and can catalyze collaborations and partnerships, fostering a vibrant research community.

Thirdly, a lesser fraction of the publications in this field are published as book chapters (3.2 % of the total). The Book chapter often offers a comprehensive overview of the broad thematic volumes or an in-depth analysis of a special topic within the overall themes. Book chapters provide less opportunities as compared to journal or conference articles, but are relevant because they can set research within a larger framework and address interdisciplinary perspectives. This makes them ideal for consolidating content already known and introducing additional theoretical or methodological practices in depth.

This highlights the dual focus in the EV battery research domain as revealed by our analysis, where the majority of studies on the charging time of EV batteries are published in peer-reviewed journal papers and conference papers. The distribution model echoes the engineering field in that it encourages both precise academic validation and rapid broadcast of research results. However, the lesser percentage of book chapters - denoting a specialized lane - also suggests an immense scope for complete and inter-disciplinary research into the matter. These publication trends are important for EV researchers and funders as well as policy-makers to inform their strategies in kick-starting, maintaining, or consolidating their EV research gears into higher gear.

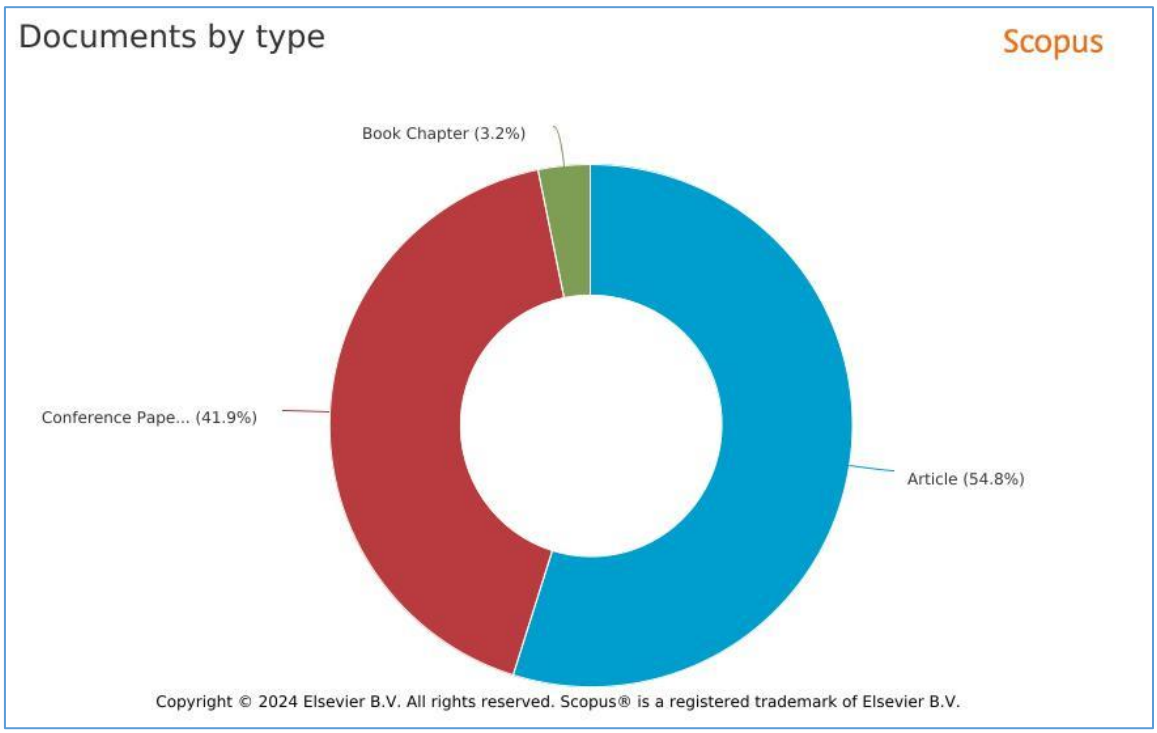

Figure 4. Publication by type
Source: Scopus database on April 2024

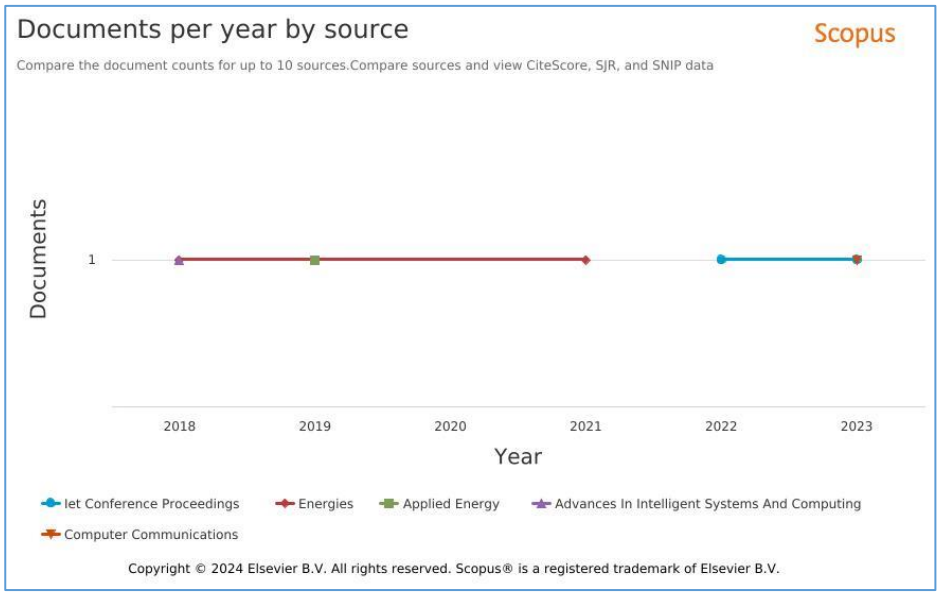

Figure 5. Top publication platforms
Source: Scopus database on April 2024

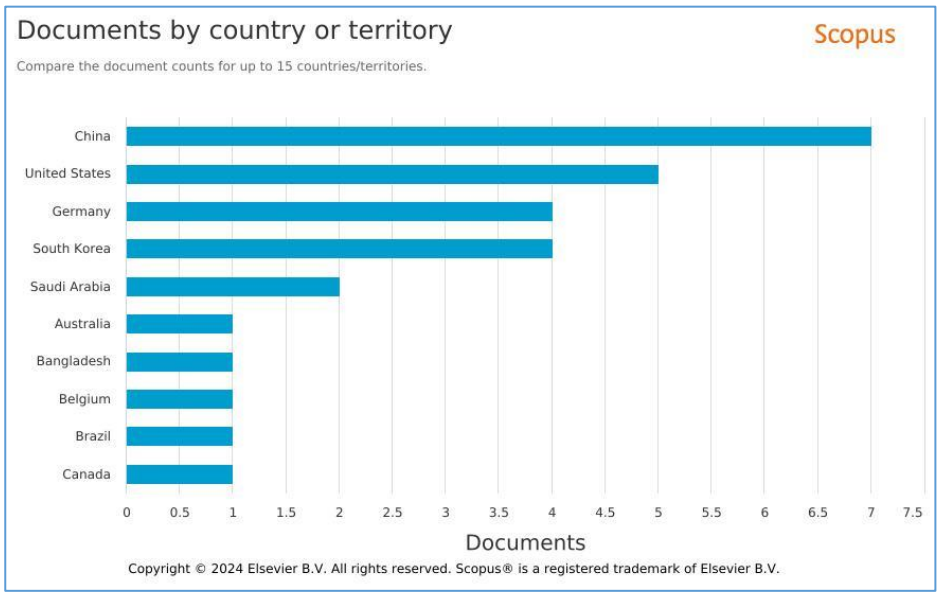

Figure 6. Top countries
Source: Scopus database on April 2024

Platforms or sources of the research are displayed in Figure 5. The corresponding authors have used a publishing model based on charging time of electric vehicle batteries. Such platforms can serve as important informational resources on the academic scene and spread knowledge within this ground.

It is an open access, multidisciplinary journal that publishes a broad range of articles in the fields of energy research and development featuring electric vehicles. As an open-access journal, it provides greater visibility and easy access for researchers globally. *Energies* is fully open access. It is also free to the authors if they publish before December 2022! Energies is an open access journal which makes it an ideal place for the authors who want their results to be widely and easily accessible for a large international audience in the field of energy technologies.

Secondly, *IET Conference Proceedings*. *IET Conference Proceedings* is a collection of 1-4 day conferences, seminars, and workshops organized or sponsored by the IET, either alone or in partnership with other organizations. Conferences are important platforms for exchanging new research findings through discussion, and networking among members of scientific academia. *IET Conference Proceedings* provides researchers with a round of prestigious publications throughout a variety of different engineering and technology disciplines allowing research to be presented amongst the hi-tech record so this means electric vehicle, etc. users will benefit from exposure to new computing techniques which might otherwise have limited coverage.

Thirdly, *Advances in Intelligent Systems and Computing*. Typically, a volume in this series represents the proceedings from an annual international conference. It spans several areas of AI, including its use in energy systems and transportation. This series aims to provide a forum for presenting and discussing the most recent trends in intelligent systems design as well as their interaction with humans, linear applications, industrial applications and case studies of adaptive intelligent

systems, including planning, optimization control or maintenance.

Fourthly, *Applied Energy. Applied Energy* is one of the leading energy engineering journals that seek to analyse applied research and applied sciences within the broad range of topics in these areas. *Applied Energy*, which publishes papers in renewable energy research, only accepts work subject to rigorous peer review and that is expected to represent a significant advance for the discipline.

Fifthly, *Computer Communications. Computer Communications* is a publication that was developed in computer networking and communication systems. Even though it is not specifically electric-vehicle-centric, it might still draw in researchers studying communication elements of EV charging systems (such as wireless charging techs) or communication protocols to manage charging infrastructure. Publishing in *Computer Communications* gives authors the lucrative opportunity to share, publicize, and make their paper accessible not only to networking and communication researchers but also to a wider computer science audience that might be interested in networking and communication technologies.

Top 5 platforms for research publication in electric vehicle battery charging time. The above analysis of the full range of charging cycles of electric vehicle batteries highlights a wide range of platforms related to various aspects of this subject, including energy, engineering, artificial intelligence, applied sciences, and computer networking. Scientists can select these platforms considering the journal or conference reach, audience, review, visibility and impact of the publication.

3.2 Global perspectives on researching charging time of the electric vehicle battery

Figure 6 provides a snapshot of the global perspective of research publications concerning the charging time in electric vehicle batteries while presenting important insights that can be gained from analyzing the data.

This list, with China in the first place of it, clearly shows the country's lead in advancing their research output on charging time for an electric vehicle battery. Partly due to extensive Chinese investment and an emphasis on electric vehicle technology, China features prominently here, with a numerically significant automotive industry and strong research infrastructure. This large body of research from China not only cements their place as a major driving force in facilitating the innovation and development in the field of electric cars worldwide, but also helps us comprehend what an extensive distributional effect they are going to make on eco-friendly mobility.

The U.S. in second place, serves as a reminder that it still does significant research work into electric vehicles. This is, in part, because of its world-class research institutions, blue-chip auto-makers and more than ample government backing for clean energy projects. Research in other countries is now also starting to accelerate, but what truly differentiates the U.S. is a concerted and integrated effort involving academia, industry, and government agencies collaborating to allow the nation to have greater influence in this research space on a global scale.

Germany and South Korea, which are tied for third place, confirm a broader commitment to sustainable transportation and technological advancement. Car enthusiast nations and who have invested big-money on EV R&D Engineered in Germany, based on South Korean advanced electronics and well-known automotive manufacturing of top-frequent car brands, both countries become a leading region for electric vehicle battery charging technology manufacturing.

Saudi Arabia is traditionally associated with the oil industry - but its strong presence among the top four countries shows a renewed focus on renewable energy and electric vehicles. Consequently, strategic investments in the nation to diversify its energy portfolio, thereby ramping down its fossil fuel dependence probably feed into its research acumen on electric vehicle charging technology.

In fifth position, they are diverse countries in terms of geography and research capacity. This research on electric vehicle technology is consistent with Australia's efforts in renewable energy and sustainable transportation. Its introduction to Bangladesh illustrates growing consciousness regarding the environment and the attempts of the adoption of better transportation options. Again because Belgium is situated in a central place in Europe and has extremely strong research infrastructure, it figures highly on the list. Sustainability motivated research in Brazil is evident by the country's ranking in reduction of carbon emissions but also in renewable fuel vehicles. Canada's inclusion highlights its efforts to advance clean energy technologies and support the transition to electric mobility.

Analysis of Figure 6 showed the worldwide publication of studies about charging time for electric vehicle battery. Key players around the world are China, the United States, Germany, and South Korea in ensuring that knowledge and innovation have evolved to ultimately meet the required infrastructure for a more sustainable mode of transportation. The wide range of nationalities underlines the global, collaborative, and interdisciplinary research needed on electric vehicle technology.

The data presented in Figure 7 results in profound revelations into the organizational landscape of research publications on the electric vehicle charging time of batteries.

Hankuk University of Foreign Studies, Rheinisch-Westfälische Technische Hochschule Aachen, and Beijing Jiaotong University are the top 3. These institutions have made significant research contributions to electric vehicle battery charging time. South Korea's Hankuk University of Foreign Studies has proablably mobilized this knowledge in the field, particularly in engineering and technology. Rheinisch-Westfälische Technische Hochschule Aachen is located in Aachen, Germany, that specializes in technical coursework with an emphasis on engineering research, including automotive technology and sustainable mobility. China is world's largest auto market, and with its vast clean energy and transportation infrastructure investments, Beijing Jiaotong University stands on the leading edge of research on electric vehicles.

INCORPORER, Institut du Véhicule Innovant, TÉO Taxi, and SERES EVS hold second place in each category, signaling a movement towards electric vehicle technologies. INCORPORATE may be a research consortium or company dedicated to innovation in electric vehicle charging systems. Institut du Véhicule Innovant, likely based in France, focuses on cutting-edge research in automotive technology, including electric vehicles. TEO Taxi and SERES EV possibly represent companies or initiatives specializing in electric vehicle manufacturing or services, indicating industry involvement in research publications on charging time optimization.

Key Laboratory of Artificial Intelligence and Personalized

Learning in Education of Henan Province, Mississippi State University, Univerza v Mariboru feature prominently in the second tier, highlighting their contributions to the research landscape. The Key Laboratory of Artificial Intelligence and Personalized Learning in Education of Henan Province, China, underscores the intersection of artificial intelligence and electric vehicle technology, reflecting the interdisciplinary nature of research in this field. Mississippi State University in the United States likely contributes research expertise in energy systems and automotive engineering, particularly in optimizing charging time for electric vehicles. Univerza v Mariboru, located in Slovenia, demonstrates the global reach of research efforts in electric vehicle technology, indicating collaboration and knowledge exchange across borders.

Figure 7 reveals a diverse array of organizations actively engaged in research on the charging time of electric vehicle batteries, spanning academia, industry, and research consortia. The presence of leading universities, research institutes, and companies underscores the collaborative nature of innovation in electric vehicle technology, with contributions from institutions worldwide. This analysis underscores the importance of interdisciplinary collaboration and industry-academia partnerships in advancing knowledge and driving innovation in sustainable transportation.

The data presented in Figure 8 provides valuable insights into the top researchers contributing to electric vehicle battery charging time.

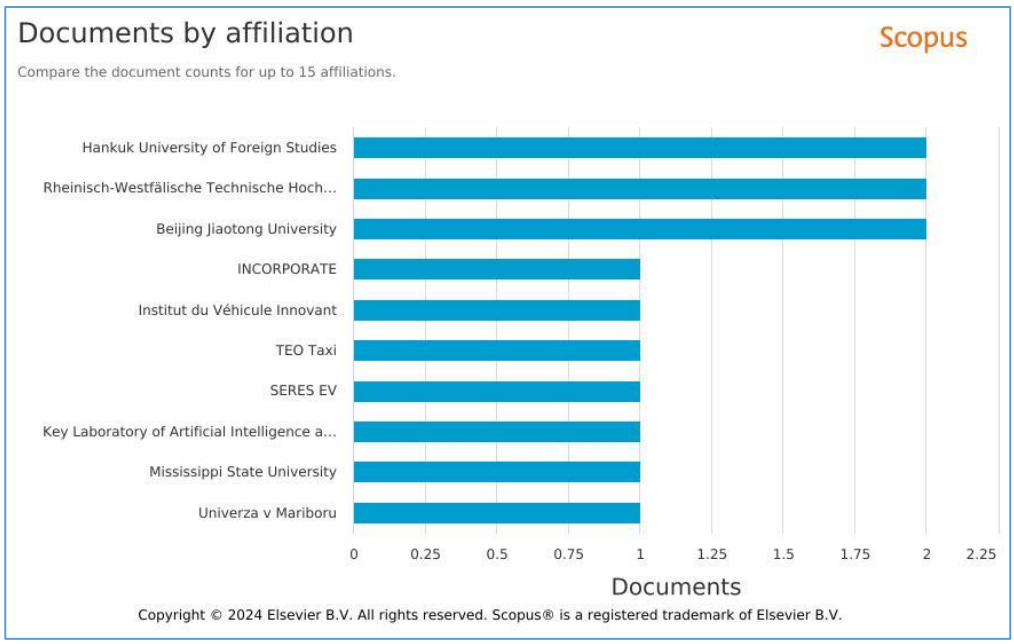

Figure 7. Top affiliation
Source: Scopus database on April 2024

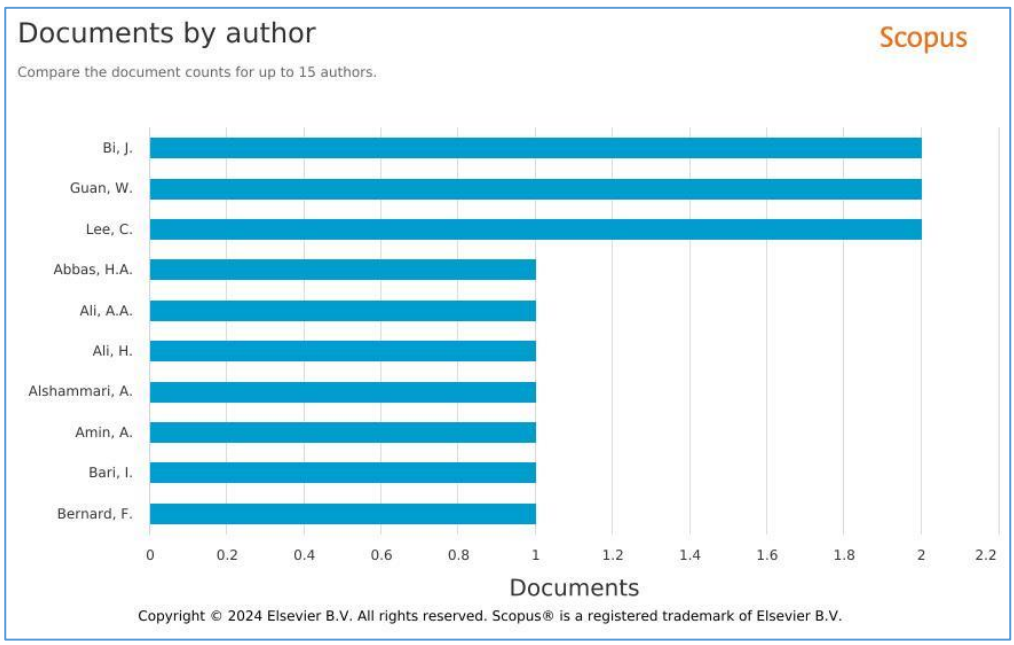

Figure 8. Top reseachers
Source: Scopus database on April 2024

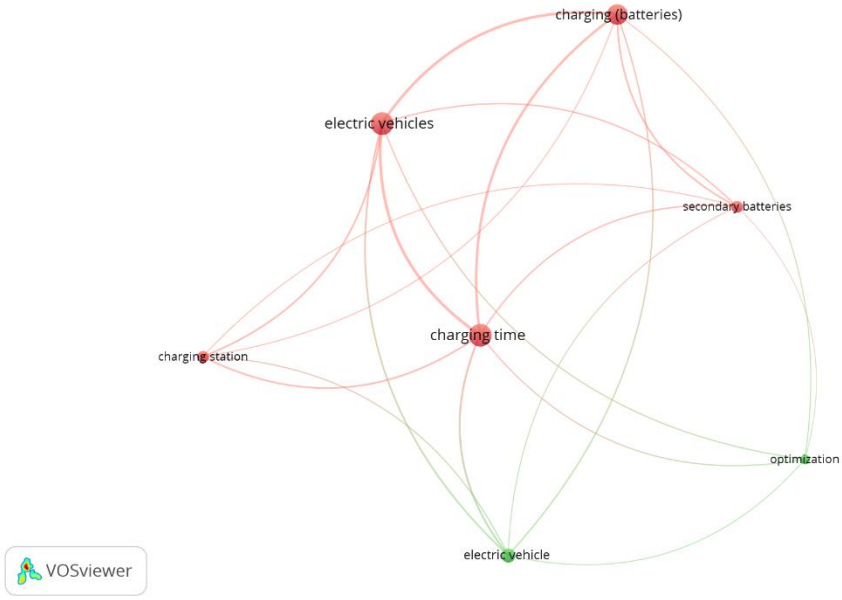

Figure 9. Network visualization
Source: VOSviewer

Firstly, Bi and Guan from Beijing Jiaotong University, China [19, 20], and Lee from Hankuk University of Foreign Studies, South Korea [21, 22], occupy the top position, indicating their significant contributions to advancing knowledge in electric vehicle battery charging time. Bi and Guan, from Beijing Jiaotong University, China, likely leverage the institution's robust research infrastructure and expertise in electric vehicle technology to produce impactful research in this field. Similarly, Lee, from Hankuk University of Foreign Studies, South Korea, contributes to the global understanding of charging time optimization, benefiting from South Korea's leadership in electric vehicle adoption and research.

Abbas (National University of Sciences and Technology, Pakistan) [23], Ali (Al-Ayen Iraqi University, AUIQ, Iraq) [23], Ali (University of Technology, Pakistan) [24], Alshammari (Al-Imam Muhammad Ibn Saud Islamic University, Saudi Arabia) [25], Amin (Mirpur University of Science and Technology, Pakistan) [24], Bari (Military Technological College, Oman) [24], and Bernard (Université Laval, Quebec, Canada) [26]: These researchers collectively occupy the second position, highlighting the global nature of research collaboration in the field. From South Asia, Abbas and Ali from Pakistan, and Ali from Iraq, and Amin from Pakistan have recently added to the increasing literature. Alshammari's inclusion represents Saudi Arabia's involvement in electric vehicle research. Bari's contribution from Oman underscores the global nature of research collaboration in electric vehicle technology. Bernard's presence in Canada reflects the country's commitment to clean energy and innovation.

In summary, Figure 8 highlights the contributions of top researchers from diverse geographic regions to the field of electric vehicle battery charging time. These researchers represent a global collaboration aimed at advancing knowledge and driving innovation in sustainable transportation. Their collective efforts underscore the interdisciplinary nature of research in electric vehicle technology, spanning fields such as engineering, materials science, and computer science. This analysis underscores the importance of international collaboration and knowledge exchange in addressing the challenges of electric vehicle adoption and promoting sustainable mobility solutions worldwide.

3.3 Thematic areas

The bibliometric analysis uncovers a unique perspective on the charging time of electric vehicle batteries, with a limited volume of publications. This scarcity of research highlights the novelty of our findings and the need for more identifiable themes. Utilizing VOSviewer, Figure 9 presents two distinct thematic clusters, Cluster 1 in red and Cluster 2 in green, which represent the predominant themes emerging from the literature.

3.3.1 Cluster 1 analysis

Cluster 1 encompasses charging (batteries), charging stations, charging time, electric vehicles, and secondary batteries. This cluster indicates a focused exploration of the charging process, infrastructure, and time optimization concerning electric vehicle batteries. The prominence of secondary batteries underscores the significance of research to enhance battery performance and charging efficiency.

3.3.2 Cluster 2 analysis

Cluster 2 primarily revolves around electric vehicles and optimization. While overlapping with themes in Cluster 1, this cluster underscores the broader context of electric vehicle optimization, encompassing diverse aspects such as energy efficiency, route optimization, and overall system performance enhancement. The presence of electric vehicles as a central theme reaffirms the overarching focus of the literature on the electric vehicle domain.

3.3.3 Implications

Firstly, the identified thematic clusters underscore the concentrated research efforts toward addressing challenges

and optimizing the charging process for electric vehicle batteries. Secondly, the convergence of themes in both clusters highlights the multidisciplinary nature of electric vehicle research, necessitating collaboration between battery technology experts, transportation engineers, and optimization specialists. Thirdly, while the research landscape is relatively nascent, the delineated themes provide a foundation for future investigations, particularly in areas such as fast charging technology, battery management systems, and integration with renewable energy sources.

Despite the limited volume of publications, the identified thematic clusters elucidate key research themes and pave the way for further exploration and innovation in the field. This underscores the need for more research in this area. Collaborative efforts across disciplines are essential to drive advancements in electric vehicle technology and optimize charging processes, ultimately facilitating the widespread adoption of sustainable transportation solutions.

The analysis provided suggests significant insights into the emerging trends within the field. Figure 10 portrays themes colored in yellow, namely charging (batteries), electric vehicles, charging time, and optimization, as relatively novel subjects. This indicates a growing interest or a recent shift in focus towards these areas within the domain under consideration. The prominence of these themes may suggest an increasing recognition of their importance or relevance within the field.

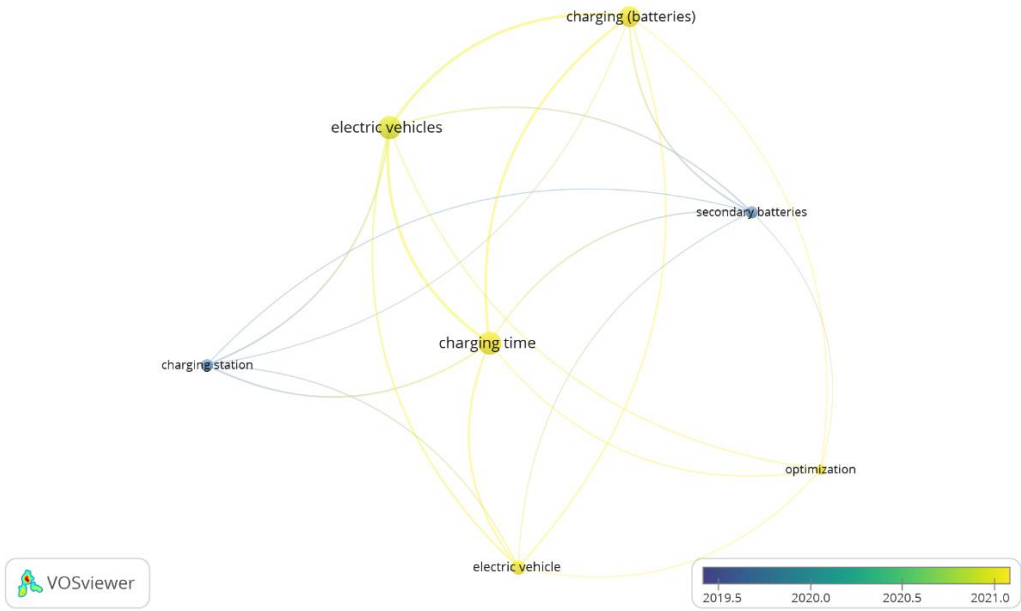

Figure 10. Overlay visualization
Source: VOSviewer

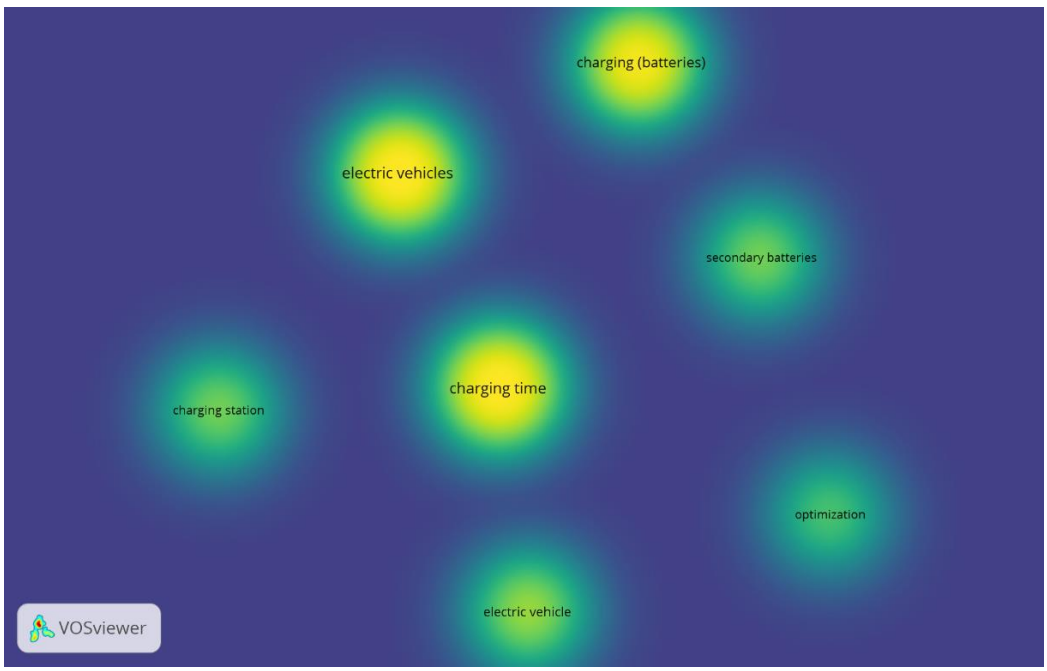

Figure 11. Density visualization
Source: VOSviewer

Furthermore, Figure 11 illustrates that the optimization theme, particularly concerning the charging time of electric vehicle (EV) batteries, stands out as an area that could be more explored compared to other themes. This observation highlights a potential gap or opportunity for further research and development. Optimizing charging time will likely become increasingly crucial, given the emphasis on electric vehicles' efficiency, sustainability, and practicality.

In summary, the investigation identifies relevant topics in the area of interest, e.g., automotive and charging technology, as main focus points. On the other side, it emphasizes more research needs to be done, especially in order to decrease the charging time of EV batteries. Such research is not only imperative to correct possible deficiencies but presents an abundance of opportunities for tremendous growth in the area.

This discussion section brings up a potential gap or opportunity for further research and development. With the focus on the efficiency, sustainability, and utility of electric vehicles, optimizing charging time is gaining more and more importance. As such, an underexplored area where future work could expand and be innovative is in more nuanced stories about this theme. Findings within the field bring up specific themes, mainly to do with electric vehicles and charging technology on one hand, and also highlight ample opportunities for how to decrease the charging time of EV batteries. This research is required to help fill in the gaps, and represents a vital piece of the puzzle that stands between us and substantial progress.

3.4 Identifying research gaps and emerging areas of interest

The analysis offers useful information on the continuously changing research scenario regarding the charging time estimation of electric vehicle (EV) batteries, thus enabling various research gaps and promising research avenues. Now, the fact that this domain warrants more publications indicates that it is a large research gap: in other words, it is an area not studied to its minimum within EVs broadly speaking. The scarcity of literature in this field amplifies the need for further research work for providing solutions to these challenges and optimal charging.

Secondly, the emerging areas of interest are:

(1) Fast-Charging Technology.

With faster charging becoming more and more attractive to improve the experience of users and support the adoption of EVs, there is a considerable need for rapid charging technologies that can achieve very short charging times, yet maintain the health and performance of the battery.

(2) Battery Management Systems (BMS).

This work opens further research avenues in the space of optimizing battery management systems based on smart algorithms and control strategies for enhanced charging efficiency, which might be directed towards taking care of cell aging, and extended battery life cycles while reducing charge times.

(3) Integration with Renewable Energy Sources.

With the movement towards sustainable transportation on the rise, there is growing demand to combine such EV charging infrastructure with renewable energy sources - namely solar and wind power. Work in this field is focused on creating intelligent grid solutions and power management that can help in optimizing the recharge process using renewable energy.

(4) Grid Integration and Demand Response.

Given that the way to guarantee power grid stability and economy energy consumption is combining with EV exit, it is necessary to understand the relationship between EV charging demand and grid operations. Research of the hour has been going on driving behaviour, vehicle to grid technologies, smart charging protocols etc to contain adverse impact on power distribution networks due to EV charging.

(5) Materials Science and Battery Technologies.

Impacts of innovations on charging performance and energy density efforts in this area of research focus on producing new types of electrode materials, electrolytes, and battery structures that allow for quicker charging without sacrificing safety or dependability.

Effective methods of studying the research gaps and corresponding to this, last but not least, emergent areas demand interdisciplinary collaboration. This can prompt novel solutions by engaging cross-disciplinary teams of experts in the fields of battery technology, electrical engineering, materials science, renewable energy systems, computer sciences, and energy economics to develop new approaches in charging times and advancing sustainable urban mobility solutions.

Prospective research roadmap: First, we are going to develop dedicated techniques to comprehend the profound mechanisms that manage the charging processes inside the EV battery cells; electrochemical kinetics, thermal management, and battery degradation. Next, we will investigate the incorporation of sophisticated control algorithms, machine learning methods, and model predictive control (MPC) to implement intelligent charging systems that can learn from user behaviors and adjust their operation accordingly, depending on pre-set user preferences or grid constraints/situation and real-time dynamic energy pricing. Then, we study the socio-economic considerations of EV charging time optimization, discussing potential consumer behavior change, infrastructure planning and policy intervention to ensure fair access to clean charging and encourage widespread EV penetration. Finally, we need to develop international collaboration and knowledge exchange activities to harness the diversity of technical expertise and resources needed to address global challenges related to EV charging infrastructure delivery & operation. In turn, that adds up to one big contribution from all of us towards a more sustainable transportation future.

Consequently, while this paper qualitatively provides an important snapshot of the current state of research on electric vehicle battery charging times through a bibliometric analysis, there is still much more to discover and to innovate upon. Addressing the research gaps identified in this report and fostering interdisciplinary collaboration can be used to stimulate research further toward achieving these outputs closely related to EV charging technology as well as operating a global sustainable transportation system.

3.5 Future research directions

We present a robust future research agenda in view of already identified research gaps and new interest areas. This roadmap may pave a useful way for tackling these gaps and hopefully contribute to the field of EV technology, battery management and sustainable transportation in a significant manner.

Future research opportunities include developing and

further optimizing and upgrading next-generation fast-charging technologies. It is no longer speculative. It is pragmatic in our contemporary world. This includes new materials for both electrodes and electrolytes, new charging approaches, and better thermal management systems. Their long-term goal is to develop materials, electrodes, and cells with ultra-fast charging while simultaneously maintaining the safety and longevity of batteries needed for applications in electric vehicles for sustainable transport.

Overall, developments toward adaptive and dynamic Battery Management Systems (BMS) algorithms could be explored in parallel. This part of the research involves designing and developing BMS systems that are able to change charging parameters from time to time. These adjustments are based on what the company claims is a real-time battery health monitor, the temperature of the surroundings, and "charging networks," as well as variables from users, which all work together to make charging more efficient and prolong the life span of batteries.

Additionally, research can focus on development of energy management systems (EMS). The integration of EV charging infrastructure with renewable energy sources and advanced grid technologies was promised to be seamless for these systems. Other areas of emphasis would include optimizing charging schedules to align with the availability of renewable energy and demand response, as well as exploring grid-connected storage solutions that could help stabilize the grid in the face of a growing volume of EVs.

While investigating the influence of human factors on behavior and preferences for EV charging is another important research trend. That would involve expensive user studies on charging time, convenience, and especially pricing. Understandings derived from such studies can guide the way for user friendly charging solutions, promoting mass-scale adoption of EVs. Beyond this, the promise of new business models and incentive structures to encourage optimal charging behaviour may reveal substantial benefits as well.

Well-to-wheel life cycle analysis of EV batteries - current challenges clarity is essential for effective regulation and decision-making with respect to battery production, procurement, and recycling. Future work may, therefore, include quantifying the environmental impacts of a wider range of charging configurations, materials sourcing, and end-of-life battery management approaches.

In addition, the study must make a detailed examination of how policy interventions and regulatory frameworks will affect how infrastructure for EV charging is deployed and maximized. Assessment of the impact of incentive programs, infrastructure investments and standardization efforts are essential to speed up the transition toward electric mobility with equal opportunities for access and an environmentally sustainable result.

Cross-disciplinary collaboration also requires considerable efforts to develop a comprehensive and comprehensible EV charging technology research and innovation integration agenda. The expert contribution is critical to this operation. Actions in this domain may include creating international research networks, coordinating multi-national projects, and enabling a dialogue between academia, industry, government, and civil society. Through jointly mapping these future research directions, we will be able to build on the previous work, identify research gaps, and drive advancements in EV charging technology - leading to a more rapid transition to an equitable, efficient electric transportation system.

4. CONCLUSIONS

The moment of charging for electric vehicle (EV) has become one of the critical research frontiers towards sustainable transportation solutions. The bibliometric analysis greatly contributes to providing a detailed examination of the developing scenario related with this subject and therefore would serve as a useful resource for understanding trends, profile, global perspectives, thematic aspects, research lacuna and future areas.

Analysis shows an increase in the number of works on optimal EV charging times, and besides these, different directions from different academic disciplines such as engineering, informatics, energy research, and mathematics. These (peer-reviewed journal articles and conference papers) forms of publication are seen as scholarly validated products that also support fast dissemination of research findings. However, the publication landscape does not deny the value given by book chapters in lifting curtains into thematic areas more comprehensively.

The examination of the rising demand for charging time optimization in EVs has portentous implications for smart city design and sustainable transportation planning. An interdisciplinary approach to electric vehicle technology is further confirmed by viewing the affiliated fields of interest, including engineering, computer science, mathematics, and energy research. This collaboration will stimulate innovation in EV charging infrastructure, supporting the larger mandate of smart cities and cleaner modes of transport.

China is closely followed by the US, Germany, and South Korea, among others, on a global scale in terms of increased focus from EV battery charger manufacturers as the investments by these nations towards clean energy and transformation innovation. Academic institutes and research center are major contributors to Academic and Industry/Government collaboration, resulting in new advancements.

As demonstrated by the thematic analysis, charging infrastructure and EV optimization form two distinctive clusters that demonstrate the multi-faceted research in this field. In sum, fast charge technology as a research gap and possible areas of interest for further work that arises during this review are the following: fast charge technology, battery management, and system, integration with renewable energy sources, stationary storage systems and materials science which can be explored through national/international studies.

The present study using bibliometric analysis presents novel, useful insights into the changing contours of research focusing on EV charging time optimization. Our review of trends, features, and perspectives at a worldwide level deepens the understanding of sustainable mobility options by identifying efficient charging processes with key relevance. The designated research voids and realms presumably on the cusp of wider exploration allow not only a strategic roadmap for research in the future but also can be understood as actionable and practical issues that should prove relevant to both practitioners and researchers.

The results point to increasing interest in reducing the time needed for EV charging, with notable contributions from various fields of academia and international leaders in clean energy and mobility innovation. Although the number of publications was limited, the identified thematic clusters still provide an outline of prominent research themes and offer a path toward continued investigation and advancement in this

domain. It is necessary to achieve breakthroughs in both the field of electric vehicle technology as well as charging processes so that it becomes attractive for the masses, and this requires interdisciplinary cooperation.

The study has several limitations, most obviously the reliance upon available biblometric data, which is bound to be incomplete and hence may not accurately reflect the totality of research output in the case. The same reasons mentioned above, like different sources of data, indexing, and quality of metadata, will create bias in the analysis. In addition, the study is confined to bibliometric analysis only, which might not capture potentially valuable qualitative insights and perspectives that would require using other research methods. Corresponding to other systematic scoping reviews this limitation could prevent us from catching certain nuances or contextual factors that shape research on optimizing EV charging times. In addition, the analysis is limited to peer-reviewed journal articles, conference papers, and book chapters, which may omit important findings from other print sources such as reports, theses, or preprints. This might skew the coverage of the field, which is particularly relevant given its varying interdisciplinary nature. The study also recognizes leaders in the research of EV battery charging time on a global level, but due to strong academic infrastructure and funding worldwide, it might have become biased towards content from regions outside emerging economies or areas less visible in scholarly databases.

Based on the research gaps and new topics of interest revealed, a detailed future research roadmap is presented. This roadmap has the ability to investigate and deal with these loopholes effectively and, as such, can be a game changer in the rise of electric vehicle technology, battery management, and the transportation field. Theoretical but absolutely necessary in the world as we know it, developing and refining fast-charging technologies of the future is an exercise that needs to be taken very seriously. As such, future research should be dedicated to investigating new electrode and electrolyte materials, original charging strategies, and heightened thermal management approaches. Ultimately, this will be designed to enable ultra-fast charging while safeguarding the batteries at all times, allowing for more than enough supply for many years. It is vital for the widespread adoption of the electric vehicle (EV) and a sustainable transport system. This highlights the need for interdisciplinary and exchange initiatives in this field to propel research and innovation on EV charging technology.

Given the limitations noted in the study, a number of suggestions for future research can be made to overcome these issues and improve analysis completeness. One: The massive footprint that can be left by using sources of data that are additional to those in bibliometric provides hope. The future research should use non-traditional data sources, such as industry reports, technical manuals, patent databases, and online forums. This way, they are able to reduce the bias found in bibliometric data while getting a more detailed overview of the research landscape across many different sources.

Second, a more comprehensive update to the literature is warranted, with future studies needing to include types of publications beyond peer-reviewed journal articles, conference papers, and book chapters. This might require a systematic exploration and synthesis of literature from grey literature sources, institutional repositories, pre-print servers, and conference proceedings to capture a more comprehensive picture of the research terrain.

Future research should also draw more broadly from across regions of the world, as well as build on the bias towards those with greater academic presence. A mindful effort to include research contributions from emerging economies, developing regions, and other than English language publications facilitates deeper analysis and fosters increased inclusivity in scholarly discourse.

Second, potential longitudinal studies in different periods of time would be able to map the changes in trends, priorities and collaborations evolution about EV charging time optimization research. Reseachers can use this information to examine how the volume of research output, thematic clusters and geographical distribution change over time to better understand the topic's dynamic nature and find new research directions.

At the same time, the future research roadmap that is sketched out in this article is intended as more than a guiding structure for individual researchers; it is also a rallying cry to action. The paper provides a roadmap to fill the identified research gaps and investigate new topics, encouraging all researchers and practitioners to join. If we focus on developing and improving the next-gen fast charging, R&D on adaptive battery management systems and integrating EV charging with renewable sources of energy, we can all collectively move forward in having a sustainable transportation ecosystem. Further research on human factors of EV charging behavior, life cycle assessment of EV batteries and policy intervention should be part of this joint future research effort.

ACKNOWLEDGMENT

This academic article stems from an investigation funded by the Applied Research Grant provided by the Directorate of Research, Technology, and Community Service (DRTPM) within the Ministry of Education, Culture, Research, and Higher Education (Kemendikbudristek) of the Republic of Indonesia. The grant numbers associated with this study are 180/E5/PG.02.00.PL/2023 and 018/SP2H/RT-MONO/LL4/2023.

REFERENCES

[1] Sun, C.X., Li, T.X., Low, S.H., Li, V.O.K. (2020). Classification of electric vehicle charging time series with selective clustering. Electric Power Systems Research, 189: 106695. https://doi.org/10.1016/j.epsr.2020.106695

[2] Shi, J.Z., Tian, M., Han, S.W., Wu, T.Y., Tang, Y.F. (2022). Electric vehicle battery remaining charging time estimation considering charging accuracy and charging profile prediction. Journal of Energy Storage, 49: 104132. https://doi.org/10.1016/j.est.2022.104132

[3] Wang, J.N., Li, F.X., Fang, X., Wang, W.B., Cui, H.T., Zhang, Q.W., She, B.X. (2024). Electric vehicles charging time constrained deliverable provision of secondary frequency regulation. IEEE Transactions on Smart Grid, 15(4): 3892-3903. https://doi.org/10.1109/TSG.2024.3356948

[4] Hemavathi, S., Shinisha, A. (2022). A study on trends and developments in electric vehicle charging technologies. Journal of Energy Storage, 52: 105013. https://doi.org/10.1016/j.est.2022.105013

[5] Chen, X.H., Xiao, H.T., Shi, X.J., Zhao, Q., Xu, X.W., Fan, P., Xiao, D.Q. (2023). Bibliometric analysis and visualization of transdermal drug delivery research in the last decade: Global research trends and hotspots. Frontiers in Pharmacology, 14: 1173251. https://doi.org/10.3389/fphar.2023.1173251

[6] Nguyen, T.T., Ha, L.L., Nguyen, L.H., Vu, L.G., Do, H.T., Boyer, L., Fond, G., Auquier, P., Latkin, C.A., Ho, C.S.H., Ho, R.C.M. (2023). A global bibliometric analysis of intimate partner violence in the field of HIV/AIDS: Implications for interventions and research development. Frontiers in Public Health, 11: 1105018. https://doi.org/10.3389/fpubh.2023.1105018

[7] Liu, L., Cui, H.L., Nie, Y.K. (2023). Cite space-based bibliometric analysis of green marketing. Sustainability, 15(12): 9840. https://doi.org/10.3390/su15129840

[8] Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., Lim, W.M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. Journal of Business Research, 133: 285-296. https://doi.org/10.1016/j.jbusres.2021.04.070

[9] Donthu, N., Kumar, S., Pandey, N., Lim, W.M. (2021). Research constituents, intellectual structure, and collaboration patterns in Journal of International Marketing: An analytical retrospective. Journal of International Marketing, 29(2): 1-25. https://doi.org/10.1177/1069031X211004234

[10] Purwanto, E., Iskandar, Y., Bhaktiar, P. (2024). A bibliometric analysis on energy efficiency and conservation. In E3S Web of Conferences, 517: 03001.

[11] Şimşek, A.İ., Taşdemir, B.D., Koç, E. (2023). A bibliometric analysis and research agenda of the location of electric vehicle charging stations. Business & Management Studies: An International Journal, 11(2): 610-625. https://doi.org/10.15295/bmij.v11i2.2246

[12] Ullah, I., Safdar, M., Zheng, J., Severino, A., Jamal, A. (2023). Employing bibliometric analysis to identify the current state of the art and future prospects of electric vehicles. Energies, 16(5): 2344. https://doi.org/10.3390/en16052344

[13] Aliusta, H. (2023). Bibliometric analysis of research on the relationship of accounting and information systems/technologies. İşletme Araştırmaları Dergisi, 15(2): 797-815. https://doi.org/10.20491/isarder.2023.1619

[14] Purwanto, E., Uddin, N., Nugraha, H. (2024). Hybrid solar-electric cart efficiency enhancement: A bibliometric analysis. In E3S Web of Conferences, 506: 11001.

[15] Pitaloka, E., Purwanto, E., Suyoto, Y.T., Dwianika, A., Anggreyani, D. (2024). Bibliometrics analysis of green financing research. International Journal of Sustainable Development and Planning, 19(3): 853-865. https://doi.org/10.18280/ijsdp.190305

[16] Dwianika, A., Purwanto, E., Suyoto, Y.T., Pitaloka, E. (2024). Bibliometrics analysis of green accounting research. International Journal of Energy Economics and Policy, 14(1): 349. https://doi.org/10.32479/ijeep.15055

[17] Purwanto, E., Irawan, A.P. (2023). Bibliometric analysis of electric vehicle adoption research: Trends, implications, and future directions. International Journal of Safety and Security Engineering, 13(5): 789-800. https://doi.org/10.18280/ijsse.130503

[18] Purwanto, E. (2024). A bibliometric analysis of trends and collaborations in autonomous driving research (2002-2024). Mechatronics and Intelligent Transportation Systems, 3(2): 85-112. https://doi.org/10.56578/mits030202

[19] Bi, J., Wang, Y.X., Sun, S., Guan, W. (2018). Predicting charging time of battery electric vehicles based on regression and time-series methods: A case study of Beijing. Energies, 11(5): 1040. https://doi.org/10.3390/en11051040

[20] Shao, S., Guan, W., Ran, B., He, Z.B., Bi, J. (2017). Electric vehicle routing problem with charging time and variable travel time. Mathematical Problems in Engineering, 2017(1): 5098183. https://doi.org/10.1155/2017/5098183

[21] Park, H., Lee, C. (2024). An exact algorithm for maximum electric vehicle flow coverage problem with heterogeneous chargers, nonlinear charging time and route deviations. European Journal of Operational Research, 315(3): 926-951. https://doi.org/10.1016/j.ejor.2023.12.019

[22] Lee, C. (2021). An exact algorithm for the electric-vehicle routing problem with nonlinear charging time. Journal of the Operational Research Society, 72(7): 1461-1485. https://doi.org/10.1080/01605682.2020.1730250

[23] Kamona, S.M.H., Abbas, H.A., Ibrahim, A.A., Mohammed, N.Q., Ali, A.A., Mohammed, B.A., Hamza, M.S. (2024). A comparative study on charging time of electric vehicles optimization using cuckoo search and particle swarm optimization methods. Journal of Operation and Automation in Power Engineering, 11(Special Issue). https://doi.org/10.22098/JOAPE.2023.13832.2066

[24] Usman, M., Tareen, W.U.K., Amin, A., Ali, H., Bari, I., Sajid, M., Seyedmahmoudian, M., Stojcevski, A., Mahmood, A., Mekhilef, S. (2021). A coordinated charging scheduling of electric vehicles considering optimal charging time for network power loss minimization. Energies, 14(17): 5336. https://doi.org/10.3390/en14175336

[25] Alshammari, A., Chabaan, R.C. (2023). Metaheruistic optimization based Ensemble machine learning model for designing Detection Coil with prediction of electric vehicle charging time. Sustainability, 15(8): 6684. https://doi.org/10.3390/su15086684

[26] Rioux-Paradis, K., Gaudreault, J., Redmond, C., Otomo-Lauzon, K., Bernard, F., Deschenes, A., Quimper, C.G., Boivin, S., Blouin, P. (2018). Learning from historical data to predict electric vehicle taxi consumption and charging time. In 2018 Winter Simulation Conference (WSC), Gothenburg, Sweden, pp. 1216-1217. https://doi.org/10.1109/WSC.2018.8632353