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Charging Forward: Mapping the Global Research Landscape of Electric Vehicle Infrastructure

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ABSTRACT

The global transition to electric mobility necessitates a robust charging infrastructure, a topic that has seen exponential growth in academic research. To navigate this expanding landscape, this study conducts a comprehensive scientometric analysis of 4,243 documents from the Scopus database (1994–2024). Using VOSviewer, we map publication trends, collaboration networks, and the intellectual structure of the field. The findings reveal a surge in publications since 2010, with the United States, India, Germany, and China as the most prolific contributors. Co-citation analysis identifies the foundational authors, while keyword co-occurrence analysis uncovers four primary thematic clusters: (1) Charging Technology and Hardware, (2) Grid Integration and Management, (3) Optimization and Planning, and (4) Policy and Socio-economics. Furthermore, a temporal analysis of keywords highlights a clear research trajectory, shifting from foundational concepts towards emerging frontiers like machine learning and wireless power transfer. This review provides a definitive map of the EV charging infrastructure research domain, offering valuable insights for researchers and policymakers shaping the future of sustainable transportation.

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INTRODUCTION

The transition to electric vehicles (EVs) is a critical component of global strategies to decarbonize the transportation sector and achieve a clean energy transition (Zhang et al., 2021). Central to this transition is the development of a robust, accessible, and efficient charging infrastructure, which plays a pivotal role in overcoming barriers to EV adoption, such as range anxiety and convenience (Dadhwal et al., 2021). As the deployment of EVs accelerates, the complexity of planning and integrating charging infrastructure into existing power grids has grown, necessitating a multidisciplinary research approach that spans engineering, energy policy, economics, and computer science (Ozturk, 2010).

The academic literature on EV charging infrastructure has expanded rapidly, making it challenging for researchers and practitioners to keep abreast of the evolving knowledge landscape. This inherent complexity underscores the need for advanced analytical tools to synthesize and map the vast body of research (Darko et al., 2020). Scientometric analysis offers a powerful methodology for systematically reviewing a research field, allowing for the quantitative assessment of publication trends, collaboration networks, and thematic evolution (Aria & Cuccurullo, 2017; Van Eck et al., 2010). By analyzing publication data, it is possible to identify influential works, authors, and institutions, and to visualize the intellectual structure of the research domain (Martinez et al., 2019).

While numerous studies have reviewed specific aspects of EV technology and energy saving (Dadhwal et al., 2021), a broad scientometric overview of the entire EV charging infrastructure field remains limited. This study aims to fill that gap by providing a comprehensive

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analysis of the research landscape. The main objectives are to:

1. Illustrate the temporal growth of research in the field;
2. Identify the most influential documents, journals, organizations, and countries;
3. Map the collaborative networks among key research actors;
4. Uncover the dominant and emerging research themes through keyword analysis (San-Juan-Heras et al., 2024).

By providing a clear map of the current research landscape, this study offers valuable insights for the academic community and supports evidence-based decision-making for advancing sustainable electric mobility and energy planning (Pohekar & Ramachandran, 2004).

METHODOLOGY

This study employs a scientific mapping approach to analyze the research outputs in the field of EV charging infrastructure from 1994 to 2024, based on publications indexed in the Scopus database. The methodology combines a bibliometric search with a scientometric analysis using VOSviewer software to visualize the results.

Data Collection

The publication data for this review was extracted from the Scopus database, which is recognized for its extensive coverage of peer-reviewed literature across multiple disciplines (Aghaei Chadegani et al., 2013; Singh et al., 2021). The search was conducted using the query string: (TITLE-ABS-KEY ("electric vehicle" "charging infrastructure")) for publications between 1994 and 2024. To ensure relevance, the search was limited to the English language and restricted to the subject areas of Engineering, Energy, Chemical Engineering, and Economics. This process yielded a final dataset of 4,243 documents, comprising articles, conference papers, reviews, and other document types.

Science Mapping and Analysis

The bibliometric mapping was performed using VOSviewer (version 1.6.17), a software tool designed for creating and visualizing large-scale bibliometric networks (van Eck & Waltman, 2010). VOSviewer is adept at constructing networks based on co-authorship, co-citation, bibliographic coupling, and keyword co-occurrence, representing the relationships between items as nodes within a network (Eck & Waltman, 2014). The association strength normalization method was used to account for variations among nodes (Eck & Waltman, 2009).

To ensure the clarity and relevance of the network visualizations, minimum thresholds were applied to filter the data. These thresholds represent the minimum number of documents, citations, or co-occurrences required for an item to be included in the analysis, thereby focusing the maps on the most significant contributors and themes. The specific values used for each analysis type are detailed in Table 1.

Table 1: VOSviewer Thresholds

Analysis Type	Unit of Analysis	Counting Method	Total	Threshold	Final
Bibliographic Coupling	Documents (Citations)	Full	3170	200	88(57)
	Sources (Documents)	Full	414	5	66
	Organizations (Documents)	Full	2520	10	81
	Countries (Documents)	Full	99	5	66
Co-citation	Cited Authors	Full	1515	10	58
Co-occurrence	Author Keywords	Full	6084	20	48

The analyses conducted in this study include:

1. Bibliographic Coupling: This analysis was performed for documents, sources

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(journals), organizations, and countries. Two items are bibliographically coupled if they both cite the same third item, which helps identify clusters of related research (Bendigiri & Rao, 2023).

2. Co-citation Analysis: This was used to identify influential authors. When two authors are cited together in the reference list of a third document, they are co-cited, indicating a thematic link between their work.
3. Keyword Co-occurrence Analysis: This method was used to identify the main research themes. When keywords appear together in multiple publications, it signifies a strong conceptual link, and VOSviewer groups them into thematic clusters (San-Juan-Heras et al., 2024).

RESULTS AND DISCUSSION

Overview of Publication Trends

The field of EV charging infrastructure has experienced significant growth, as illustrated in Figure 1. Research output remained sparse until the mid-2000s, after which a steady increase began, culminating in an exponential rise from 2010 onwards. This rapid expansion aligns with the global push for sustainable transportation and a broader clean energy transition (Zhang et al., 2021). The surge in publications reflects a growing academic and industrial focus on addressing the challenges associated with the mass adoption of EVs, including grid stability, charging optimization, and the development of effective business models.

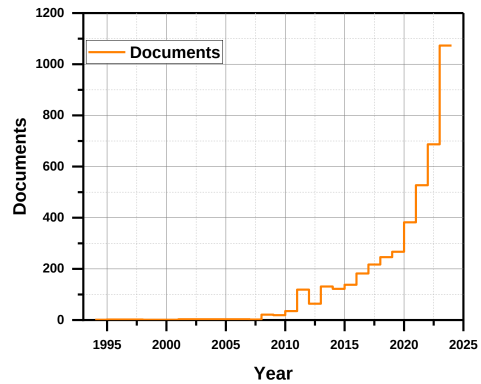

Figure 1: Publication trend on EV charging infrastructure

Analysis of Most Influential Documents

The influence of a publication is often measured by its citation count, which reflects its impact on subsequent research (Eck & Waltman, 2014). Table 2 lists the top 10 most cited documents in the field. The leading paper by Yilmaz et al. (2013a), a review of battery charger topologies, has accumulated 2,726 citations, highlighting the foundational importance of charging technology in this domain. Other highly cited works address socio-economic factors influencing EV adoption (Sierzchula et al., 2014), grid integration challenges (Das et al., 2020), and the potential of vehicle-to-grid (V2G) technologies (Tomić & Kempton, 2007) The prominence of review articles in this list underscores their crucial role in synthesizing knowledge and guiding the direction of research in a rapidly evolving field.

Table 2: Top 10 documents by citation on EV charging infrastructure

Document	Title	DOI	Document Type	Citations
(Yilmaz & Krein, 2013a)	Review of battery charger topologies, charging power levels, and infrastructure for plug-in electric and hybrid vehicles	10.1109/TPEL.2012.2212917	Review	2726
(Sierzchula et al., 2014)	The influence of financial incentives and other socio-	10.1016/j.enpol.2014.01.043	Article	1094

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Document	Title	DOI	Document Type	Citations
	economic factors on electric vehicle adoption			
(Das et al., 2020)	Electric vehicles standards, charging infrastructure, and impact on grid integration: A technological review	10.1016/j.rser.2019.109618	Review	917
(Tomić & Kempton, 2007)	Using fleets of electric-drive vehicles for grid support	10.1016/j.jpowsour.2007.03.010	Article	910
(Yilmaz & Krein, 2013b)	Review of the impact of vehicle-to-grid technologies on distribution systems and utility interfaces	10.1109/TPEL.2012.2227500	Review	894
(A. Ahmad et al., 2017)	A Comprehensive Review of Wireless Charging Technologies for Electric Vehicles	10.1109/TTE.2017.2771619	Article	856
(Tu et al., 2019)	Extreme Fast Charging of Electric Vehicles: A Technology Overview	10.1109/TTE.2019.2958709	Article	764
(Su et al., 2012)	A survey on the electrification of transportation in a smart grid environment	10.1109/TII.2011.2172454	Review	724
(R. R. Kumar & Alok, 2020)	Adoption of electric vehicle: A literature review and prospects for sustainability	10.1016/j.jclepro.2019.119911	Review	689
(Kalghatgi, 2018)	Is it really the end of internal combustion engines and petroleum in transport?	10.1016/j.apenergy.2018.05.076	Review	603

The bibliographic coupling analysis of these documents, shown in Figure 2, reveals distinct research clusters. For instance, the work of Yilmaz et al. (2013b) forms a large cluster focused on the technical aspects of charging hardware, while another cluster around Sierzchula et al. (2014) connects research on policy, economics, and consumer behavior.

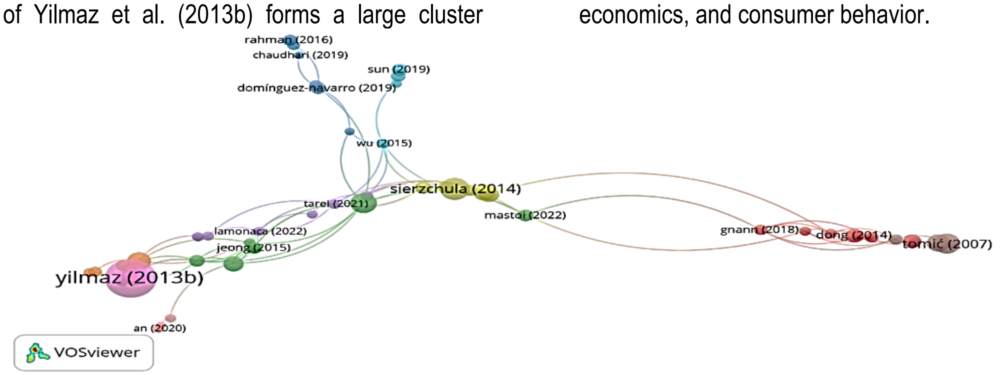

Figure 2: Bibliographic coupling of documents on EV charging infrastructure

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Leading Journals, Organizations, and Countries

Journals

The analysis of publishing sources indicates that research on EV charging infrastructure is disseminated across a wide range of journals. As shown in Table 3, Energies is the most prolific journal with 143 documents, followed by the World Electric Vehicle Journal (110 documents). However, journals like Transportation Research Part D: Transport and Environment and Applied Energy have higher citation counts despite fewer publications, indicating their significant influence in the field. The bibliographic coupling map in Figure 3 illustrates three main clusters of journals: an engineering and technology cluster (red), a transportation and environment cluster (blue), and an energy policy and sustainability cluster (green)

Table 3: Top 10 sources by documents on EV charging infrastructure

Sources	Documents	Citations	Avg. pub. Year	Links	Total link strength
Energies	143	3889	2021	65	2099
World electric vehicle journal	110	1702	2018	64	1101
Transportation research part d: transport and environment	99	7931	2020	59	2123
IET conference proceedings	78	97	2022	52	404
Sustainability (Switzerland)	71	2003	2021	63	904
Applied energy	63	6107	2019	64	1035
Energy	54	3232	2020	63	960
Energy policy	47	5547	2018	57	988
Transportation research part c: emerging technologies	46	4559	2019	54	1046

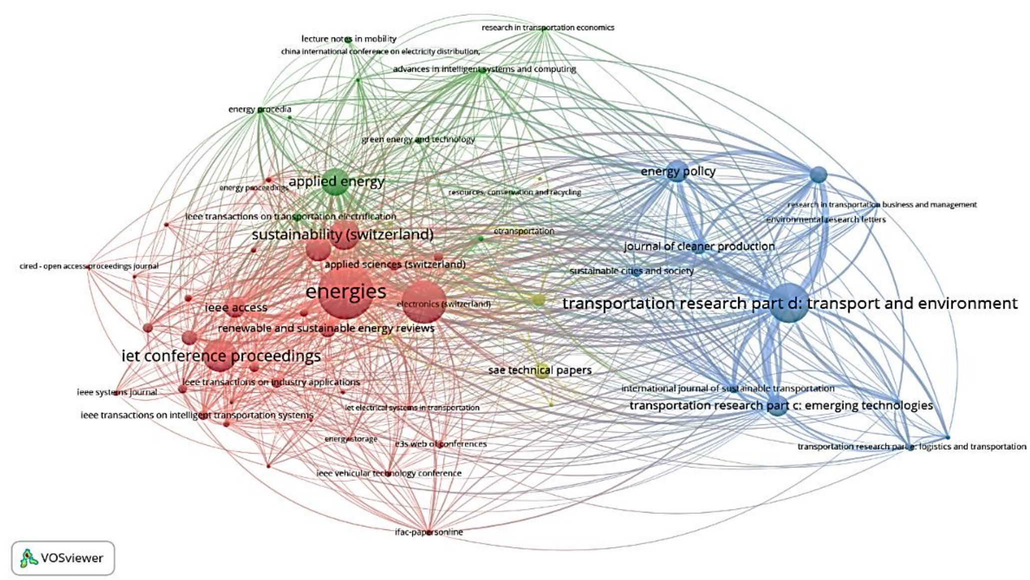

Figure 3: Bibliographic coupling of sources with documents on EV charging infrastructure

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Organizations and Countries

The institutional analysis highlights the global nature of EV infrastructure research. As shown in Table 4, German, Italian, and Chinese universities are among the most productive institutions, with Rheinisch-Westfälische Technische Hochschule Aachen leading with 48 documents. The collaboration network between these organizations is visualized in Figure 4.

Table 4: Top 10 organizations by documents on EV charging infrastructure

Organization	Documents	Citations	Avg. pub. Year	Links	Total link strength
Rheinisch-Westfälische Technische Hochschule Aachen, Aachen, Germany	48	1209	2019	77	794
Politecnico Di Milano, Milan, Italy	44	918	2021	75	465
Tsinghua University, Beijing, China	43	2029	2019	78	808
National Renewable Energy Laboratory, Golden, United States	40	2094	2019	76	673
Indian Institute of Technology Delhi, New Delhi, India	39	643	2022	74	503
North China Electric Power University, Beijing, China	38	1919	2018	74	570
Technische Universität München, Munich, Germany	36	818	2020	77	646
Oak Ridge National Laboratory, Oak Ridge, United States	35	1956	2017	74	808
University Of California, Davis, Davis, United States	29	2191	2018	67	583
Vrije Universiteit Brussel, Brussels, Belgium	28	388	2018	63	283

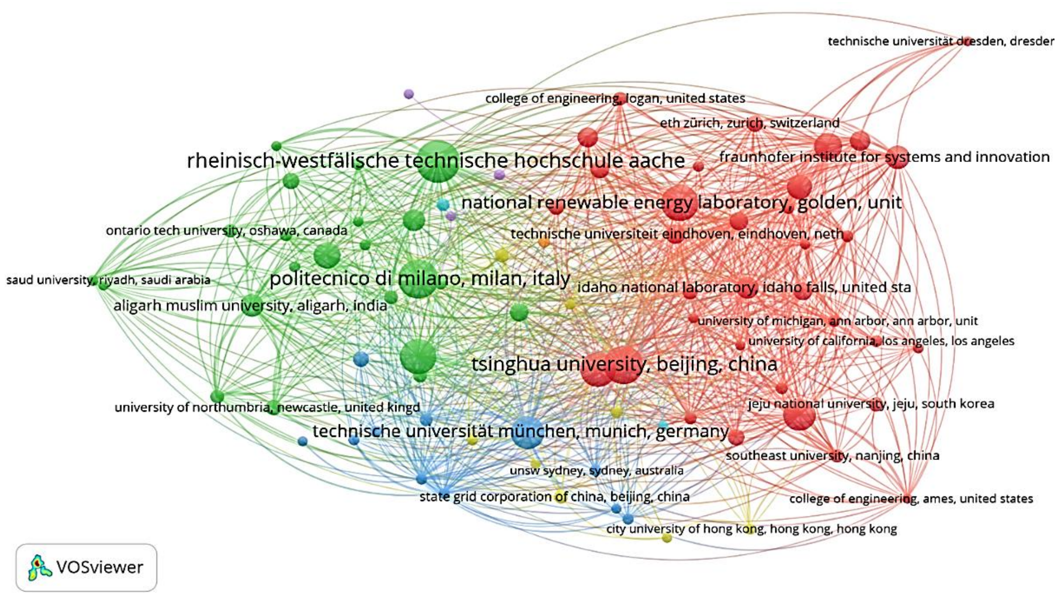

Figure 4: Bibliographic coupling of organizations with documents on EV charging infrastructure

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At the country level (Table 5), the United States is the most productive nation with 620 documents and the highest number of citations (35,226), underscoring its leading role in the field. India, Germany, and China follow in terms of publication volume, indicating strong national research programs in these countries.

Table 5: Top 20 countries by documents on EV charging infrastructure

Country	Documents	Citations	Avg. pub. Year	Links	Total link strength
United States	620	35226	2018	65	20946
India	488	10540	2022	65	15458
Germany	391	8955	2019	65	10659
China	377	16428	2020	65	14609
United Kingdom	180	6457	2020	64	7243
Italy	165	3410	2020	64	6541
Canada	133	5219	2020	65	6064
Netherlands	110	4708	2019	64	4464
South Korea	99	3269	2018	64	3529
France	89	2188	2019	64	3340
Australia	76	3218	2020	63	3299
Sweden	76	4170	2019	62	3173
Spain	65	2427	2019	62	2599
Saudi Arabia	63	4623	2021	64	3128
Belgium	55	1603	2018	61	2013
Denmark	51	2283	2020	61	2521
Japan	50	1707	2017	54	1188
Malaysia	43	2482	2020	63	2538
Switzerland	43	2237	2018	60	1593
Austria	42	1379	2018	58	1548

The country collaboration network in Figure 5 shows a dense web of international partnerships, with the US, Germany, and China acting as central hubs connecting researchers globally
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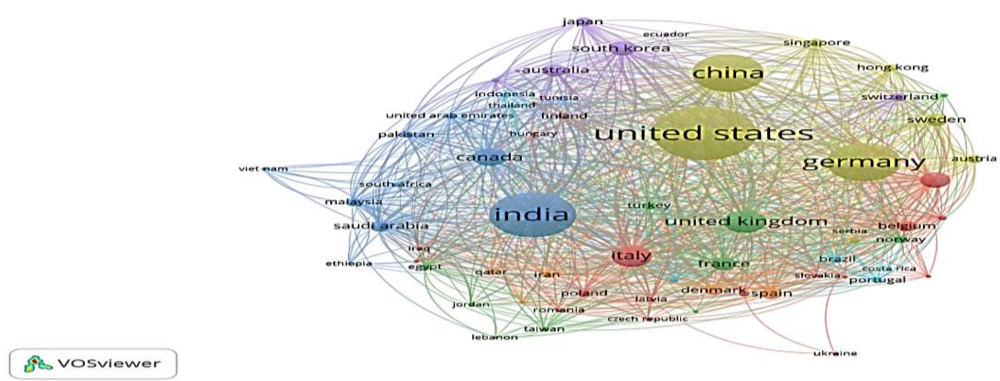

Figure 5: Bibliographic coupling of countries with documents on EV charging infrastructure

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Co-citation Analysis of Authors

The co-citation analysis reveals the intellectual pillars of the field, identifying the foundational scholars whose works are most frequently cited together by other researchers. This method effectively maps the intellectual structure of the domain. As shown in the network visualization in Figure 6 and detailed quantitatively in Table 6, authors like Willett M. Kempton (56 citations), Scott J. Hardman (47 citations), and Donna T. Chen (43 citations) are among the most influential researchers. Their high co-citation frequency indicates that their foundational contributions to concepts like V2G technology, EV adoption behavior, and charging infrastructure planning are considered seminal. These authors form the core of the intellectual network, with their works serving as essential references and conceptual starting points for new research entering the field.

Table 6: Top authors by citations on EV charging infrastructure

Author	Citations	Author	Citations	Author	Citations
Kempton, Willett M.	56	Burnham, Andrew J.	16	Peterson, Scott B.	12
Hardman, Scott J.	47	Green, Robert C.	16	Soares, Joao P.	12
Chen, Donna T.	43	Morrissey, Patrick J.	16	Sweda, Timothy M.	12
Dharmakeerthi, C.H.	38	Bessa, Ricardo J.	15	Borlaug, Brennan A.	11
Pecas Lopes, Joao A.	36	Kuby, Michael J.	15	Caperello, Nicolette D.	11
Ajanovic, A.	29	Singh, B.P.	15	Dominic Savio, A.	11
Neubauer, Jeremy S.	29	Al-Alawi, Baha M.	14	Gonzalez, Luiz G.	11
Carley, Sanya R.	25	Emadi, Ali N.	14	Putrus, Ghanim A.	11
Arias, Mariz B.	22	Gautam, Deepak S.	14	Taylor, Jason A.	11
Hannan, M.A.	22	Sanguesa, Julio A.	14	Williams, James H.	11
Richardson, David B.	22	Adler, Jonathan D.	13	Williamson, Sheldon S.	11
Boulanger, Albert G.	21	Daganzo, Carlos F.	13	Wirasingha, Sanjaka G.	11
Foley, Aoife M.	21	Mwasilu, Francis A.	13	Boesch, Patrick M.	10
Alhazmi, Yassir A.	20	Sarker, Mushfiqur R.	13	F Shaaban, Mostafa F.	10
Botsford, Charles W.	20	Sovacool, Benjamin K.	13	Hidrue, Michael K.	10
Bradley, Thomas H.	20	Bruckmann, G.	12	Sandy Thomas, C.E.	10
Lam, Albert Y.S.	20	Bryden, Thomas S.	12	Sivaraman, P.	10
Mohamed, Ahmed A.S.	17	Dijkstra, E.W.	12	Smart, John G.	10
Bauer, Gordon S.	16	Galus, Matthias D.	12		
Bonges, Henry A.	16	Needell, Zachary A.	12		

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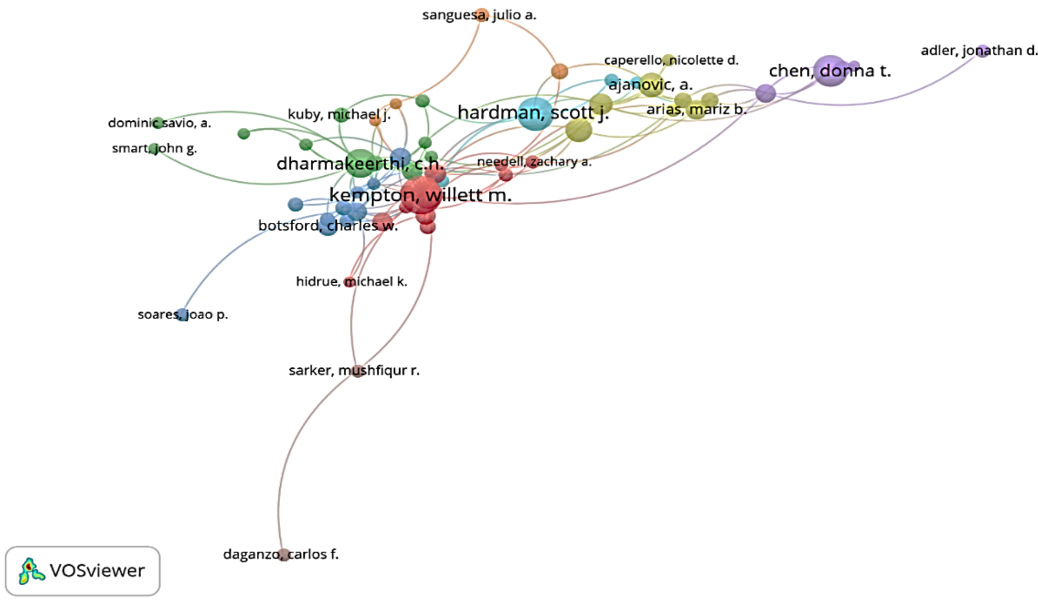

Figure 6: Co-citation of cited authors in EV charging infrastructure research

Keyword Co-occurrence Analysis and Research Themes

The co-occurrence analysis of author keywords provides a map of the dominant research themes (San-Juan-Heras et al., 2024). Figure 7 visualizes this network, where the size of a node indicates the frequency of a keyword, and the lines represent their co-occurrence in publications. As detailed quantitatively in Table 7, the most frequent keywords are “Electric vehicle (EV),” “Charging infrastructure,” “Charging station,” “Vehicle-to-grid,” and “Smart grid.” In the network visualization, the largest nodes, “electric vehicle (ev)” and “charging infrastructure,” are positioned centrally, signifying their role as the foundational concepts connecting nearly all other research topics.

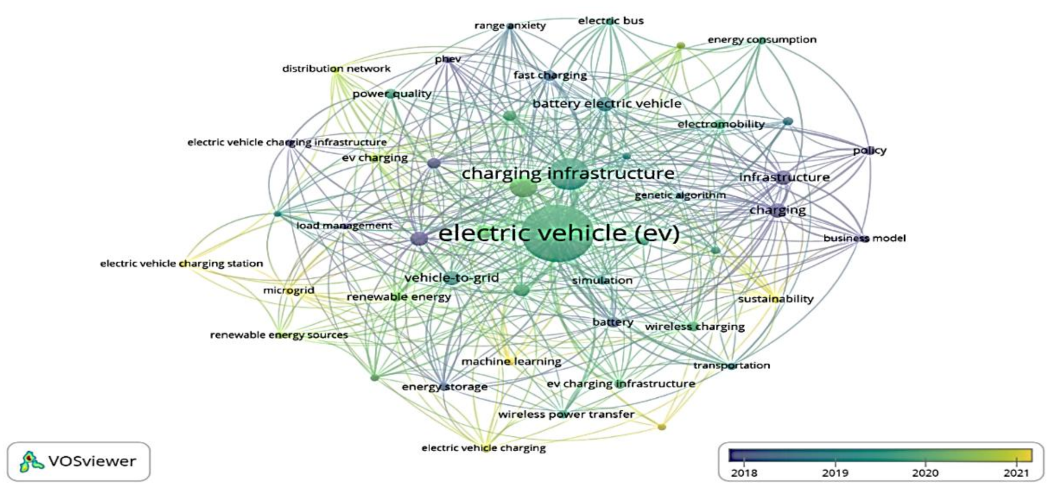

Figure 7: Co-occurrence of author keywords on EV charging infrastructure

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A temporal analysis indicated by the color of the nodes in Figure 7, reveals the evolution of research focus over time. Foundational topics like "policy" are shaded in darker blue, indicating they are well-established areas (average publication year around 2018). In contrast, keywords appearing in yellow are the most recent, highlighting emerging research frontiers (average publication year around 2021). These trending topics include "machine learning," "wireless power transfer," "sustainability," and "energy consumption." This color gradient illustrates a clear shift in the research landscape, moving from foundational policy and hardware concepts towards more advanced, data-driven, and sustainability-oriented solutions

.

Table 7: Top 10 Keywords on EV charging infrastructure

Keyword	Occurrences	Avg. pub. Year	Avg. citations	Links	Total link strength
Electric vehicle (EV)	1542	2020	36	47	1448
Charging infrastructure	476	2020	46	39	620
Charging station	229	2020	35	40	343
Battery electric vehicle	102	2019	53	31	104
Vehicle-to-grid	96	2019	53	28	153
Charging	94	2017	14	26	155
Infrastructure	93	2016	12	25	146
Smart grid	93	2017	37	33	146
Optimization	85	2020	41	33	148
Smart charging	77	2020	47	30	125

The analysis reveals several key thematic clusters:

1. Cluster 1: Charging Technology and Hardware: This theme centers on the technical aspects of charging systems. Keywords like fast charging, wireless charging, wireless power transfer, and battery are prominent. Research in this cluster focuses on developing faster, more efficient, and more convenient charging solutions, often linked to technological innovation systems (Weckowska et al., 2025).
2. Cluster 2: Grid Integration and Management: This cluster addresses the challenges of integrating EVs into the power grid. Key terms include smart grid, vehicle-to-grid (V2G), power quality, and energy storage. This research explores smart energy management and forecasting models to manage the increased load from EV charging and leverage EVs as a distributed energy resource to support grid stability (T. Ahmad et al., 2020; Shashwat et al., 2023).
3. Cluster 3: Optimization and Planning: This area focuses on the strategic deployment of charging infrastructure, often using multi-criteria decision making (MCDM) approaches (A. Kumar et al., 2017; Pohekar & Ramachandran, 2004). Keywords like optimization, simulation, and load management are central. Studies here use modeling and algorithms to determine the optimal number, type, and location of charging stations to meet demand efficiently and cost-effectively.
4. Cluster 4: Policy and Socio-economics: This theme examines the non-technical factors influencing the transition to electric mobility. Prominent keywords include policy, electric mobility, and electromobility. This research investigates the role of government incentives, user behavior, and

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economic viability in driving the development of charging infrastructure.

CONCLUSION

This scientometric analysis provides a comprehensive overview of the global research landscape for electric vehicle charging infrastructure from 1994 to 2024. The findings demonstrate that the field has grown exponentially, evolving into a highly interdisciplinary domain that integrates engineering, energy systems, transportation planning, and policy studies (Staffell et al., 2019). The analysis identified the United States, India, Germany, and China as the leading countries in terms of research productivity and collaboration. The most influential research has focused on foundational topics such as charging topologies, grid integration, and the socio-economic drivers of EV adoption. Keyword analysis revealed four major thematic clusters: charging technology, grid integration, optimization and planning, and policy. These themes reflect the core challenges and opportunities in deploying a widespread and effective EV charging network.

This review highlights a clear shift from purely technical studies towards more integrated research that considers the interplay between technology, the power grid, user behavior, and policy frameworks. Future research is likely to focus increasingly on smart charging, V2G applications, the integration of renewable energy sources with charging infrastructure, and the development of sustainable business models (S. Kumar et al., 2021). By mapping the intellectual structure of the field, this study provides a valuable reference for researchers to identify knowledge gaps and for policymakers to align strategies with the latest scientific insights, ultimately supporting the global transition to sustainable transportation.

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