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Emerging Trends In Low-Emission Urban Transport: A Bibliometric Analysis Of Sustainable Mobility Technologies

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Abstract: *This study investigates the intellectual and thematic structure of low-emission urban transport research through a comprehensive bibliometric analysis of 150 peer-reviewed articles indexed in Scopus between 2010 and 2024. Employing co-authorship, keyword co-occurrence, and co-citation network analyses, the study uncovers evolving trends in electric mobility, micromobility, charging infrastructure, and sustainability governance. The findings reveal dominant thematic clusters but also underscore persistent fragmentation, with limited integration across technological, behavioural, and policy domains. Regional analysis highlights a marked underrepresentation of institutions from Africa, Latin America, and South Asia, raising concerns about epistemic equity and contextual relevance. The study is theoretically anchored in Sociotechnical Transitions and Innovation Diffusion theories, offering a lens to interpret knowledge diffusion patterns and paradigm development within the field. It concludes by advocating for inclusive, interdisciplinary, and policy-integrated research strategies to guide sustainable mobility transitions across both Global North and Global South contexts. The bibliometric approach adopted offers a replicable framework for mapping scholarly landscapes and informing future research in emerging policy domains.*
Keywords: *Electric Vehicles (EVs), Bibliometric Analysis, Global South, Low-Emission Urban Transport, Sociotechnical Transitions, Sustainable Mobility*

1. INTRODUCTION

Urban transport systems are increasingly recognized as central to the global climate agenda, given that the sector accounts for a substantial share of greenhouse gas emissions (International Energy Agency [IEA], 2023; Vajjarapu et al. 2023).The transportation sector is a major contributor to GHG emissions, accounting for approximately one-third of emissions in the U.S. and 25% globally (Ciotti et al. 2023).Rapid urbanization, population growth, and rising demand for mobility have intensified the pressure on cities to adopt solutions that reduce environmental impacts while supporting economic and social development. This phenomenon is a double-edged sword, contributing to economic prosperity and social development while posing severe challenges to the natural environment and social systems (Voukkali et al. 2023). Innovations such as electric vehicles (EVs), shared micromobility platforms, and smart charging infrastructure are being promoted as transformative pathways for decarbonizing urban transport (Schelte et al. 2022). These technologies are not only reshaping commuting and last-mile logistics but are also redefining how cities conceptualize sustainable mobility and climate-resilient development (Beck et al. 2025).

Despite the growing momentum in this area, knowledge production in low-emission urban transport remains unevenly distributed across the globe. A significant proportion of published research originates from Europe and East Asia, while contributions from the Global South remain limited (Emodi et al. 2022; Li et al. 2022). This imbalance raises concerns about inclusivity, since developing regions face distinct infrastructural (Kirjavainen & Suopajärvi, 2025), policy (Canitez et al. 2020), and socio-economic challenges in advancing sustainable mobility transitions (Oviedo et al. (2022). Furthermore, most studies focus on isolated themes such as EV adoption, charging infrastructure, or micromobility without integrating environmental, technological, and social perspectives into a holistic framework (Adamashvili & Thrassou, 2024; Patrikiou et al. 2023). The absence of comprehensive bibliometric assessments has constrained the ability to map the intellectual and thematic evolution of this field, limiting insights into research collaborations, regional representation, and emerging gaps (Hassan et al. 2025; Tahir et al. 2025).

This study addresses these limitations by conducting a bibliometric analysis of 150 peer-reviewed publications on low-emission urban transport. Using VOSviewer and the Bibliometrix R package, the study explores co-

authorship networks, keyword co-occurrences, citation patterns, and thematic clusters to provide a comprehensive mapping of the field. The analysis is anchored in Sociotechnical Transitions Theory, which views sustainable mobility as a multi-level transformation shaped by technologies, institutions, and societal practices (Forbord & Hansen, 2020), and Innovation Diffusion Theory, which explains how new technologies such as EVs and micromobility platforms spread across regions at
varying rates (Vargo et al. 2020). These theoretical perspectives provide a foundation for interpreting bibliometric patterns in ways that extend beyond descriptive mapping to illuminate the broader dynamics of sustainability transitions. Combining MLP with interdisciplinary approaches helps address diverse perspectives and contested issues in mobility transitions.
The main objective of the study is to map the evolution of research in low-emission urban transport and to highlight underexplored areas, particularly in the Global South. Specifically, the study seeks to answer four research questions: What are the publication and citation trends in the field? Which themes dominate the discourse and how have they evolved over time? Who are the leading authors, institutions, and regions shaping the knowledge base? And what gaps persist, especially regarding geographical inclusivity? The findings contribute to theory by linking bibliometric evidence with sustainability transition frameworks, to practice by offering policymakers and urban planners' insights into collaboration and priority areas, and to methodology by demonstrating the utility of bibliometric tools for advancing research synthesis in transport and mobility studies.

2. LITERATURE REVIEW

Building on the global challenges and opportunities outlined in the introduction, recent research has increasingly focused on technological, infrastructural, and social dimensions of low-emission mobility. These studies provide insight into how innovations such as electric vehicles, micromobility, and charging infrastructure are shaping the future of sustainable transport, but they also highlight persistent gaps in geographical inclusivity and theoretical integration.

2.1 Global Advances in Low-Emission Transport

The past decade has seen accelerated advances in low-emission transport technologies as cities address rising greenhouse gas emissions and worsening urban air quality. Electric vehicles (EVs) have become central to decarbonization strategies, with research increasingly examining charging station deployment, optimization, and integration into energy systems (Feng et al., 2024). In parallel, shared battery systems have emerged as innovative solutions to address range anxiety and enhance the efficiency of EV fleets (Berg et al., 2023). Beyond cars, micromobility platforms such as e-scooters and electric bicycles have expanded rapidly, raising both opportunities for sustainable last-mile mobility and challenges related to safety and urban regulation (Walton et al., 2023).
Infrastructure innovation is another critical strand of this research. Studies have examined mobile charging robots for EVs as potential flexible charging solutions in congested cities (Wessel et al., 2024) and explored public acceptance of electric roadways as an alternative charging model (Konstantinou et al., 2023). In addition, sustainability assessments of electrified last-mile logistics highlight the role of EV-based distribution in reducing carbon footprints (Selter et al., 2024). Collectively, these advances point to a global transition toward greener, digitally enabled transport ecosystems, though the pace and scope of adoption vary significantly across regions.
Despite rapid technological progress, adoption has been uneven. High-income countries continue to dominate deployment and research, while many cities in Africa, Latin America, and South Asia face infrastructural, financial, and governance barriers (Srikanth et al., 2024). This uneven geography underscores the need for inclusive approaches that integrate not only technology and environment but also social acceptance, governance frameworks, and equity considerations in the design of low-emission mobility systems.

2.2 Role of Bibliometric Analysis in Transport and Sustainability Studies

Bibliometric analysis has become an essential method for systematically mapping scientific knowledge, identifying intellectual structures, and detecting thematic trends across disciplines. Within transport and sustainability research, it has been applied to domains such as charging infrastructure, shared mobility, and urban electrification. Bibliometric techniques covering publication performance indicators and network analyses of co-authorship, keyword co-occurrence, and citations allow researchers to trace the intellectual evolution of a field, identify emerging hotspots, and highlight collaboration networks.

In relation to low-emission transport, bibliometric approaches are particularly valuable given the fragmented nature of the literature. For example, while some studies focus on EV charging optimization (Feng et al., 2024), others emphasize shared battery systems (Berg et al., 2023) or last-mile electrification (Selter et al., 2024). A bibliometric perspective synthesizes these strands, revealing both thematic cohesion and fragmentation. For policymakers and planners, this evidence highlights priority areas, informs strategic investment, and identifies underexplored domains where more research is required.

2.3 Theoretical Framework

The transition toward low-emission transport can be interpreted through complementary theoretical perspectives. Sociotechnical Transitions Theory emphasizes that sustainable mobility is shaped by interactions between niche innovations (e.g., shared batteries, micromobility), socio-technical regimes (e.g., existing transport infrastructures, regulatory frameworks), and broader landscape pressures such as climate change and urbanization. Innovation Diffusion Theory highlights how adoption dynamics vary across contexts, explaining why public acceptance of new infrastructures like electric roadways differs significantly between regions (Konstantinou et al., 2023). Meanwhile, the Resource-Based View foregrounds the role of resource heterogeneity, suggesting that regions with advanced technological, financial, or institutional capacities are better positioned to adopt and scale low-emission mobility solutions. Together, these theories offer explanatory depth for understanding the bibliometric patterns that emerge across the literature.

2.4 Identified Gaps in Prior Reviews and Bibliometric Studies

Despite a growing body of work, important gaps remain in existing bibliometric studies of low-emission transport. First, most prior studies focus on specific technologies such as EV charging or shared micromobility, leaving limited integration across environmental, technological, and social dimensions. Second, there are clear geographical imbalances: while Europe, North America, and East Asia dominate the literature, contributions from Africa and the Global South remain marginal (Srikanth et al., 2024). Third, many reviews have prioritized descriptive metrics without linking bibliometric findings to deeper theoretical explanations of transition dynamics and adoption patterns. Finally, there is limited analysis of the policy and governance challenges that shape the success of these technologies, despite growing evidence that public response and government intervention are crucial for adoption (Luth et al., 2023).

This study addresses these limitations by conducting a bibliometric analysis that synthesizes multiple strands of low-emission transport research including EVs, micromobility, charging infrastructure, and social acceptance while explicitly engaging theoretical perspectives and highlighting global inequalities in knowledge production. In doing so, it offers a more comprehensive and policy-relevant understanding of the evolving landscape of sustainable mobility research.

3. RESEARCH METHODOLOGY

This study employed a bibliometric research design to systematically map the intellectual and thematic evolution of low-emission urban transport research. Bibliometric analysis is particularly suited for emerging fields because it enables the integration of large bodies of literature, identification of influential scholars and institutions (Esparza-Rodríguez et al. 2022, and detection of thematic clusters and trends (Bilgili & Sheu, 2022). By combining descriptive performance indicators with network-based visualization, bibliometrics goes beyond narrative reviews, providing both quantitative and relational insights into the development of a research domain.

Databases and Search Strategy

The dataset was compiled from two leading bibliographic databases: Scopus and Web of Science (WoS). These platforms were chosen due to their wide coverage of peer-reviewed publications, rigorous indexing standards, and compatibility with bibliometric software (Kasaraneni & Rosaline, 2024). Together, Scopus and WoS offer complementary strengths Scopus provides broader coverage of recent and international journals, while WoS includes historically influential works thus ensuring a more comprehensive capture of relevant literature.

The search strategy combined keywords directly linked to low-emission transport, including "electric vehicles," "micromobility," "charging infrastructure," "low-carbon mobility," and "sustainable urban transport." Boolean operators (e.g., *AND*, *OR*) and truncation symbols were applied to maximize retrieval while minimizing irrelevant records. The search was limited to the subject areas of transport, environmental sciences, energy, and engineering to maintain thematic focus.

Inclusion and Exclusion Criteria

To ensure methodological rigor, inclusion and exclusion criteria were established prior to data collection. Only peer-reviewed journal articles, conference papers, and reviews were included, since these represent validated academic contributions. Editorials, book chapters, notes, and non-peer-reviewed documents were excluded. The timeframe was restricted to 2010–2024, capturing the period in which low-emission mobility technologies particularly EVs and micromobility have gained prominence in both research and policy discourse. Publications were restricted to English-language sources for consistency and software compatibility. Duplicate records across Scopus and WoS were systematically removed to avoid double counting.

Data Extraction and Cleaning

Bibliographic data were exported in CSV and RIS formats, including author names, titles, abstracts, keywords, publication years, affiliations, citations, and references. The datasets from Scopus and WoS were merged into a unified database. Data cleaning to address issues such as inconsistencies, variations of similar terms, misspellings, extra spaces, incomplete information, and variations in citation styles followed best practices recommended in bibliometric studies (Ahmi, 2023). This involved harmonizing variations in author names (e.g., "Wang J." vs. "Wang, Jian"), consolidating institutional affiliations (e.g., "MIT" vs. "Massachusetts Institute of Technology"), and correcting inconsistencies in keyword spellings (e.g., "e-mobility" vs. "electromobility"). These steps ensured accurate representation of collaboration patterns and thematic clusters.

Analytical Tools and Techniques

Two complementary bibliometric software tools were used: VOSviewer and the Bibliometrix R package. VOSviewer is widely employed for constructing and visualizing bibliometric maps of co-authorship, co-citation, and keyword co-occurrence networks (Li & Wei, 2022). Its graphical clustering features allow researchers to identify the intellectual and thematic structure of a field. Bibliometrix R, on the other hand, provides advanced statistical and visualization capabilities, including thematic evolution analysis, historiographic mapping, and performance indicators useful for understanding how certain topics have developed and shifted within a field (Lai et al. 2025). Using both tools allowed for triangulation of results, enhancing the robustness of findings.

Bibliometric Techniques Applied

This study applied a set of interrelated bibliometric techniques to generate a comprehensive understanding of the research field. **Co-authorship network analysis** was used at the author, institutional, and country levels to reveal patterns of collaboration and the distribution of knowledge production across regions. **Keyword co-occurrence analysis** examined the relationships among concepts such as electric vehicle adoption, micromobility, charging infrastructure, and urban sustainability, thereby uncovering thematic clusters within the literature. **Thematic mapping and evolution analysis** traced the development of research topics over time, differentiating between motor themes that drive the field, emerging themes gaining attention, and declining themes that are losing scholarly focus. In addition, **citation and co-citation analyses** highlighted the most influential documents, authors, and journals, identifying the intellectual foundations that underpin research in low-emission transport. Together, these techniques provided both a macro-level overview of publication performance and a micro-level exploration of thematic linkages, offering a nuanced perspective on the intellectual structure and evolution of the field.

Reliability and Validity

To enhance the reliability and validity of the analysis, multiple measures were adopted. First, the use of two databases (Scopus and WoS) minimized selection bias and improved coverage across disciplines. Second, data cleaning protocols were rigorously applied to reduce misclassification of authors, institutions, and keywords, thereby enhancing the accuracy of network structures. Third, triangulation across VOSviewer and Bibliometrix R helped validate results by ensuring that patterns detected in one software were consistent with the other. Finally, methodological transparency was maintained by documenting search strategies, inclusion criteria, and analytical procedures, aligning with best practices in bibliometric research (Cabezas-Clavijo & Torres-Salinas, 2021). Nonetheless, limitations remain. The restriction to English-language publications may underrepresent contributions from non-English-speaking regions, particularly in the Global South. Similarly, reliance on indexed sources excludes relevant insights from grey literature or policy reports. These limitations are acknowledged but are not expected to significantly undermine the study's objective of mapping global trends in low-emission urban transport research.

4. RESULTS

This section presents the bibliometric findings derived from an analysis of 150 peer-reviewed publications on low-emission urban transport from 2007 to 2024. Drawing on data extracted from Scopus and Web of Science, the analysis covers scientific output trends, source distributions, citation impact, contributing authors and institutions, and keyword-based thematic concentrations. Where applicable, visualizations are integrated to support empirical observations.

4.1 Descriptive Bibliometric Performance

The analysis of annual publication trends reveals a clear trajectory in research development. From 2007 to 2015, the field exhibited relatively low output, with fewer than five publications recorded per year. This period corresponds to the early stage of innovation diffusion in electric mobility and urban decarbonization, when electric vehicles (EVs), micromobility systems, and charging infrastructure had not yet gained widespread academic or policy traction (Vargo et al., 2020). Research activity during these years was sparse and largely exploratory.

A moderate growth phase emerged between 2016 and 2019. During this interval, scholarly attention increased steadily, and the number of publications began to rise, with a small peak observed around 2019. This upward trend likely reflects heightened momentum following international climate agreements such as the Paris Accord, alongside the introduction of sustainability policies in major economies (Ciotti et al., 2023). Investments in EV infrastructure, battery technology, and smart city frameworks began to influence the direction and volume of academic output.

The most significant surge in research occurred between 2020 and 2023. During this period, publication frequency expanded dramatically, with 2023 marking the peak in scientific output within the dataset. Several factors contributed to this sharp increase. There was intensified global discourse around climate change, particularly the urgency of transport decarbonization (Beck et al., 2025). Simultaneously, the COVID-19 pandemic prompted widespread re-evaluation of urban mobility systems and accelerated the adoption of micromobility and electric transport solutions. The expansion of open-access publishing in sustainability-focused journals also played a role in amplifying research visibility and dissemination.

In 2024, the dataset shows a slight decline in publication volume. However, this reduction is likely attributable to data incompleteness, as the year was still ongoing at the time of data retrieval. Such indexing lags are common in bibliometric analysis and do not necessarily reflect reduced scholarly activity or interest in the field (Ahmi, 2023). These trends are visually summarized in **Figure 1,** which illustrates the annual growth in publication output over the 2007–2024 period

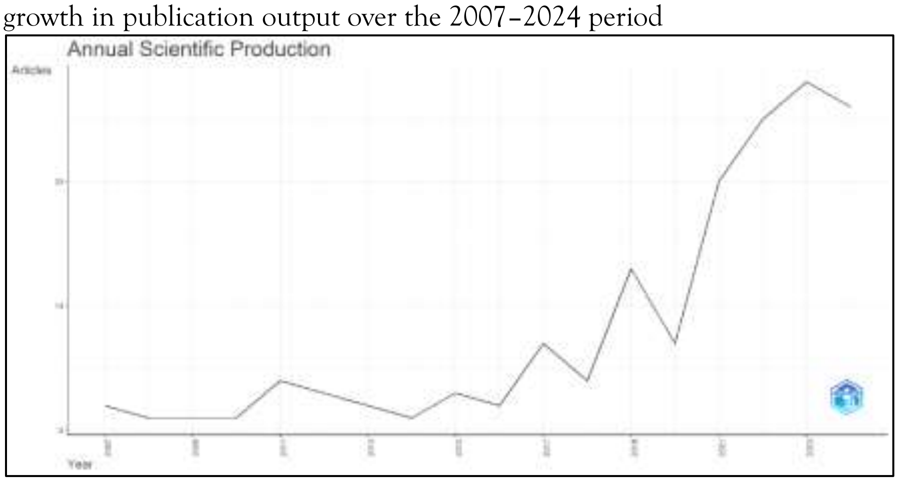

Figure 1. Annual scientific production (2007–2023).

A marked increase is observed after 2017, with rapid growth from 2020 and a peak in 2023, indicating intensified research activity in the field.

4.2 Most Productive Journals

The analysis of source impact revealed a strong concentration of publications in a few highly relevant journals. As shown in **Figure 2,** the *Journal of Cleaner Production* and *Sustainability (Switzerland)* emerged as the most productive sources, each publishing six documents related to low-emission urban transport. These journals reflect the field's strong interdisciplinary foundation, bridging sustainability science, environmental engineering, and urban policy. *Applied Energy*, *Energies*, and the *World Electric Vehicle Journal* each contributed five publications. These journals focus on energy systems and technology deployment, reinforcing the central role of electric vehicles and energy infrastructure in the discourse.

A secondary tier of journals including *Energy*, *SAE Technical Papers*, and the *International Journal of Hydrogen Energy* recorded four to three documents each. This distribution suggests a continued diversification of publishing venues that capture both technological innovation and policy-driven research. The publication patterns further indicate that the field is anchored in journals that emphasize ***green technologies, life cycle sustainability, and low-carbon urban infrastructure,*** which is consistent with the thematic focus on EV adoption, micromobility, and energy transition.

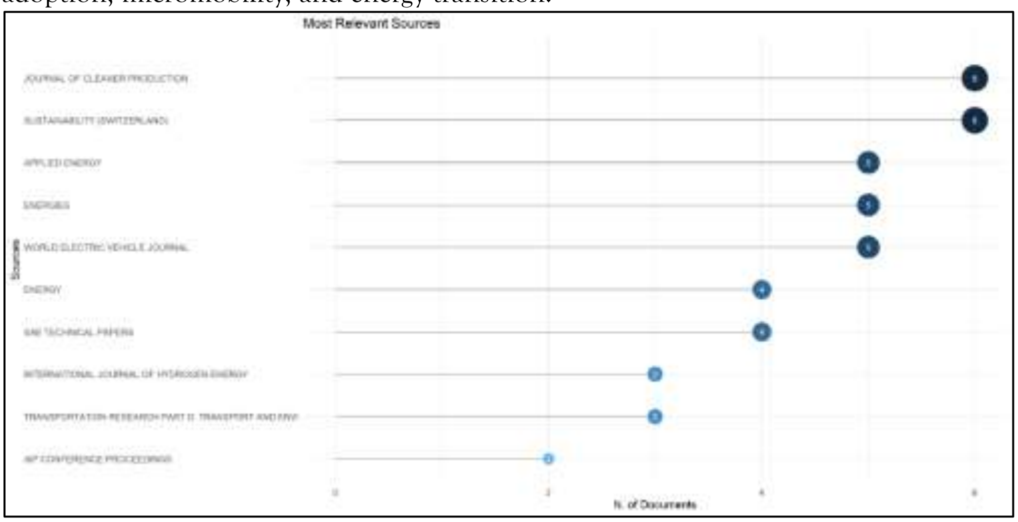

Figure 2. Most relevant publication sources.

The Journal of Cleaner Production and *Sustainability (Switzerland)* lead with six documents each, followed by *Applied Energy*, *Energies*, and *World Electric Vehicle Journal*, each contributing five.

4.3 Citation Impact and Top-Cited Publications

Citation analysis reveals critical insights into the intellectual influence and scholarly maturity of the field of low-emission urban transport. As shown in Table 1, citation performance varied considerably across years, reflecting differences in research visibility, article quality, and the time available for citations to accumulate. The metric MeanTCperArt (mean total citations per article) is particularly useful in identifying years with impactful scholarship, even when the number of published articles was low.

The year 2014 stands out prominently, with a single article achieving a total of 427 citations, resulting in a *MeanTCperArt* of 427.00 and a MeanTCperArt of 35.58. This is significantly higher than any other year in the dataset. The publication responsible for this peak is titled "Optimal Fast Charging Station Placing and Sizing," which has emerged as a landmark study in electric vehicle infrastructure planning. Its high citation volume suggests strong methodological relevance and continued application in academic and policy contexts related to EV deployment and smart grid design.

Other years also displayed notable citation performance. In 2015, three articles achieved an average of 92.33 citations each, while in 2016, two publications averaged 66.00 citations. These values indicate the rising academic interest in EV optimization models, renewable energy integration, and battery-charging technologies during that period. Although the number of publications increased in later years particularly between 2021 and 2023 the *MeanTCperArt* declined, reflecting the expected citation lag for newer publications.

The variable Citable Years further explains this dynamic. Older articles have had more time to accumulate citations, contributing to higher MeanTCperArt and MeanTCperArt values. For instance, the 2014 article has benefited from over 12 years of citation visibility, while articles from 2022 onward have had only two to three years of exposure, resulting in lower citation averages.

These citation patterns reveal temporal peaks in scholarly influence, allowing for the identification of years and publications with notable academic attention based on citation metrics alone. Figure 2 presents a visual overview of citation trends across years, illustrating fluctuations in average citation density. Table 2 provides a detailed breakdown of citation performance metrics by publication year.

Table 1. Relationships between publication years and citation performance indicators of scientific articles (2007–2024).

Year	Mean TC per Art	N	Mean TC per Year	Citable Years
2007	8.00	2	0.42	19
2008	2.00	1	0.11	18
2009	82.00	1	4.82	17
2010	0.00	1	0.00	16
2011	35.50	4	2.37	15
2012	12.00	3	0.86	14
2013	5.50	2	0.42	13
2014	427.00	1	35.58	12
2015	92.33	3	8.39	11
2016	66.00	2	6.60	10
2017	23.43	7	2.60	9
2018	33.25	4	4.16	8
2019	52.69	13	7.53	7
2020	48.29	7	8.05	6
2021	24.00	20	4.80	5
2022	16.56	25	4.14	4
2023	5.86	28	1.95	3
2024	1.62	26	0.81	2

4.4 Most Prolific Authors and Institutions

This section identifies the most productive contributors in the field of low-emission urban transport research, based on publication volume and fractional authorship metrics. The analysis offers insights into individual and institutional research leadership.

4.4.1 Most Prolific Authors

Table 2 highlights the authors with the highest number of publications in the dataset. *DEB S* leads with *five publications* and a *fractionalized contribution of 3.03*, indicating substantial lead authorship or sole authorship roles. *HAMILTON JJ* follows with a fractionalized value of *2.00* from only two articles, suggesting concentrated authorship effort. *KUMAR S* also shows notable involvement with a fractionalized score of *1.20* from two articles.

Other recurrent contributors include *WANG N*, *ZIEFLE M*, *AGATON CB*, and *GAO X-Z*, each with consistent authorship across two or more publications. The fractionalization metric allows normalization of co-authored works, offering a refined lens into individual scholarly productivity.

Table 2. Leading authors and their contribution to scientific output based on full and fractionalized articles.

Authors	Articles	Articles Fractionalized
DEB S	5	3.03
WANG N	3	0.92
ZIEFLE M	3	0.75
AGATON CB	2	0.67

BEKHET HA	2	1.00
COLLERA AA	2	0.67
GAO X-Z	2	0.70
GUNO CS	2	0.67
HAMILTON JJ	2	2.00
KUMAR S	2	1.20

4.4.2 Most Productive Institutions

Table 3 presents the top institutional affiliations based on total article output. *RWTH Aachen University* and *University of Michigan* are the most productive, each contributing 12 articles to the field. *Stanford University* closely follows with 11 publications, indicating a strong institutional focus on electric mobility and sustainable urban transport innovation. Notably, institutions from Germany (RWTH Aachen, Technical University of Darmstadt), the United States (Michigan, Stanford, California), and China (Tongji University, Beijing Institute of Technology) dominate the rankings, reflecting geographic clusters of research excellence. The presence of Chitkara University and Warsaw University of Technology also signals emerging centres of scholarly activity in this domain.

Table 3. Leading institutional affiliations and their scientific contributions based on number of published articles.

Affiliation	**Articles**
RWTH AACHEN UNIVERSITY	12
UNIVERSITY OF MICHIGAN	12
STANFORD UNIVERSITY	11
TECHNICAL UNIVERSITY OF DARMSTADT	9
UNIVERSITY OF CALIFORNIA	9
TONGJI UNIVERSITY	6
WARSAW UNIVERSITY OF TECHNOLOGY	5
BEIJING INSTITUTE OF TECHNOLOGY	4
BEIJING KEY LABORATORY OF ENERGY ECONOMICS AND ENVIRONMENTAL MANAGEMENT	4
CHITKARA UNIVERSITY	4

4.5 Geographic Distribution

Figure 3 presents the geographic distribution of scholarly output based on the country affiliations of corresponding authors. The chart differentiates between *Single Country Publications (SCP)* authored entirely within one country and *Multiple Country Publications (MCP)*, which reflect international collaborations. The data provides valuable insights into the global landscape of research activity in the domain of sustainable mobility and transport technologies. The results reveal that *China* is the most productive country, contributing the highest number of documents, with a significant majority classified as SCPs. This indicates a strong domestic research base and institutional investment in transport-related innovation. *The United States* follows closely, displaying a relatively balanced distribution between SCPs and MCPs, suggesting a combination of internal research capacity and international engagement.

Germany ranks third and demonstrates a high number of MCPs, reflecting the country's strong emphasis on cross-border collaboration, possibly influenced by its central position in Europe and active participation in EU-funded research programs. The *United Kingdom* also shows a similar collaborative profile, further highlighting the regional integration of research efforts.

Other notable contributors include *India, South Korea*, and *Poland*, all of which show higher levels of SCPs, pointing to nationally driven research agendas. Conversely, countries like *Switzerland, Australia,* and *Austria* show no MCPs in this dataset, indicating an inward-focused approach or underrepresentation in cross-border publications within the timeframe reviewed. At the lower end of the distribution, countries such as *Canada, Denmark*, and several Nordic nations have modest levels of output, but their presence in the dataset illustrates the global relevance of the topic.Overall, this distribution underscores the *dominance of Asia, North America,* *and Western Europe* in driving scholarly discourse in this field. It also reflects differing collaboration cultures where some countries prioritize domestic efforts while others engage heavily in international partnerships.

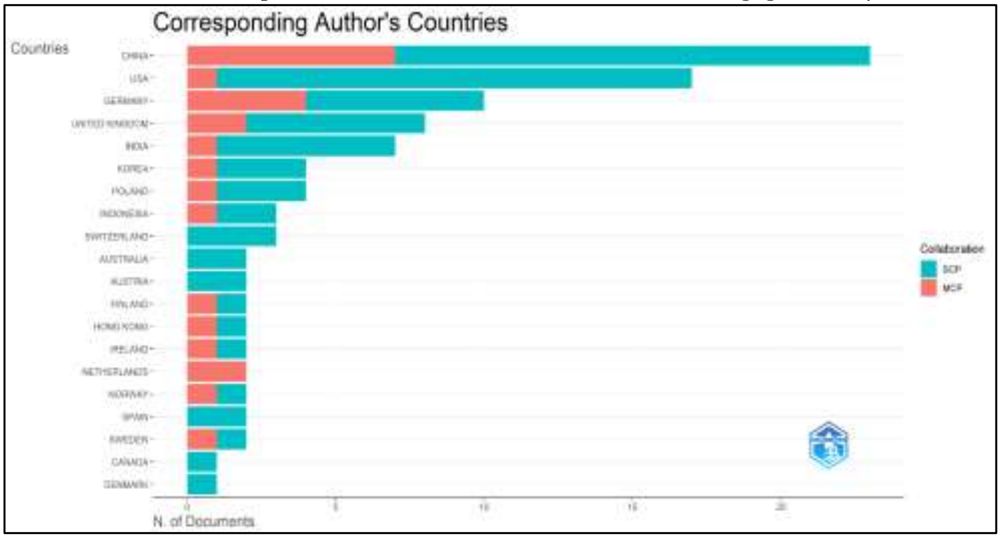

Figure 3. Distribution of corresponding authors by country.

China, the USA, and Germany lead in publications, with both single-country (SCP) and multiple-country (MCP) collaborations, reflecting dominant roles in international research output.

4.6 Co-authorship Network Analysis

Figure 4 presents a country-level co-authorship collaboration network highlighting the structure and intensity of scholarly collaboration among the most productive countries in the field. The size of each node corresponds to the volume of publications attributed to a country, while the thickness of the connecting lines represents the strength of co-authorship ties.

The analysis reveals that ***China*** emerges as the most central and prolific contributor, exhibiting strong bilateral collaboration links with ***the United States, Germany, Australia,*** and ***South Korea***. These partnerships suggest China's pivotal role in shaping the global research agenda within this thematic domain. The ***United States*** and ***Germany*** also appear as prominent actors, maintaining robust linkages not only with China but also with each other and other European nations, indicating a well-integrated transatlantic research network. The ***United Kingdom*** forms another influential hub with strong ties to ***India, Taiwan***, and several European collaborators such as ***Belgium*** and ***France***. This cluster reflects a blend of Commonwealth-driven collaborations and intra-European research connections.

On the periphery***, Indonesia*** appears relatively isolated, with limited co-authorship interactions, primarily linked to ***Denmark***. Similarly, ***Italy*** and ***Sweden***, despite their participation, demonstrate lower connectivity, forming smaller, less integrated clusters. These patterns underscore both the ***globalization of research*** and the ***asymmetry in collaborative strength***, with a few countries acting as anchors of multinational research ecosystems while others remain marginal or emerging players in the network.

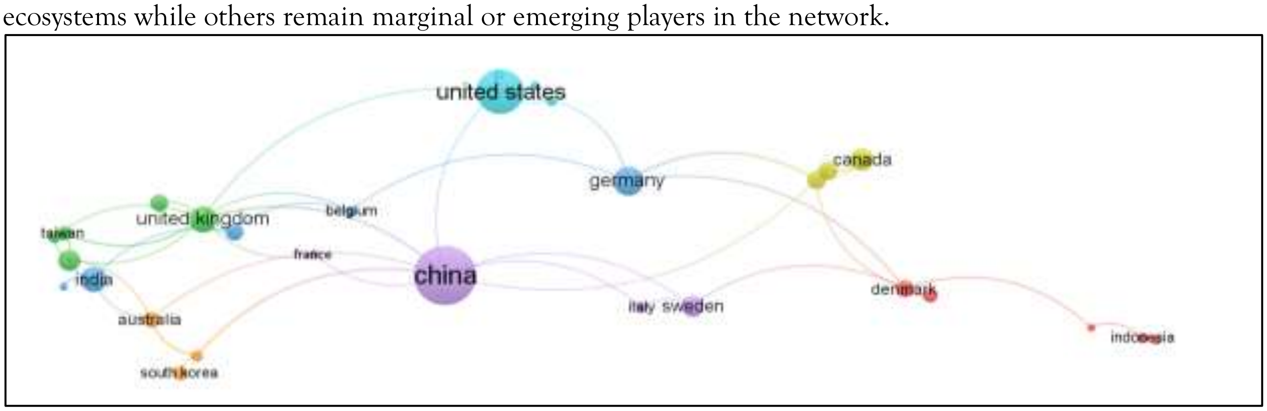

Figure 4. International co-authorship network among countries.

The map illustrates major collaborative clusters, with China, the United States, and the United Kingdom serving as central hubs, linking multiple regions, and reflecting the global structure of research partnerships.

4.7 Keyword Co-occurrence and Thematic Clusters

Figure 5 presents a keyword co-occurrence network, highlighting the most frequently used terms and their relational patterns across the literature. The size of each node corresponds to the frequency of a keyword's appearance, while the lines between nodes indicate co-occurrence strength. Thematic clusters are represented by different colors, each signifying a distinct area of research emphasis. The term *"electric vehicles"* dominates the network, functioning as a central node connected to multiple clusters. It is strongly linked with keywords such as *"charging infrastructure," "secondary batteries,"* and *"public acceptance,"* reflecting the intersection of technological, infrastructural, and social dimensions in EV-related research.

Another prominent theme centers on energy storage technologies, with closely connected terms including *"battery recycling," "energy storage,"* and *"secondary batteries."* This suggests sustained research interest in the environmental and efficiency aspects of EV power systems. Thematic density also increases around the keywords *"public acceptance"* and *"sustainability,"* revealing a significant focus on societal attitudes and environmental integration. Peripheral yet emerging terms such as *"machine learning," "responsible sourcing,"* and *"developing countries"* point to nascent research trajectories. These areas suggest growing attention to data-driven approaches, ethical sourcing in the EV supply chain, and geographic expansion of research interest toward lower-income regions.

Overall, the keyword co-occurrence map reveals a field characterized by both established research domains and evolving areas of inquiry. The clustering structure demonstrates a moderate level of thematic fragmentation, indicating opportunities for greater interdisciplinary integration in future work.

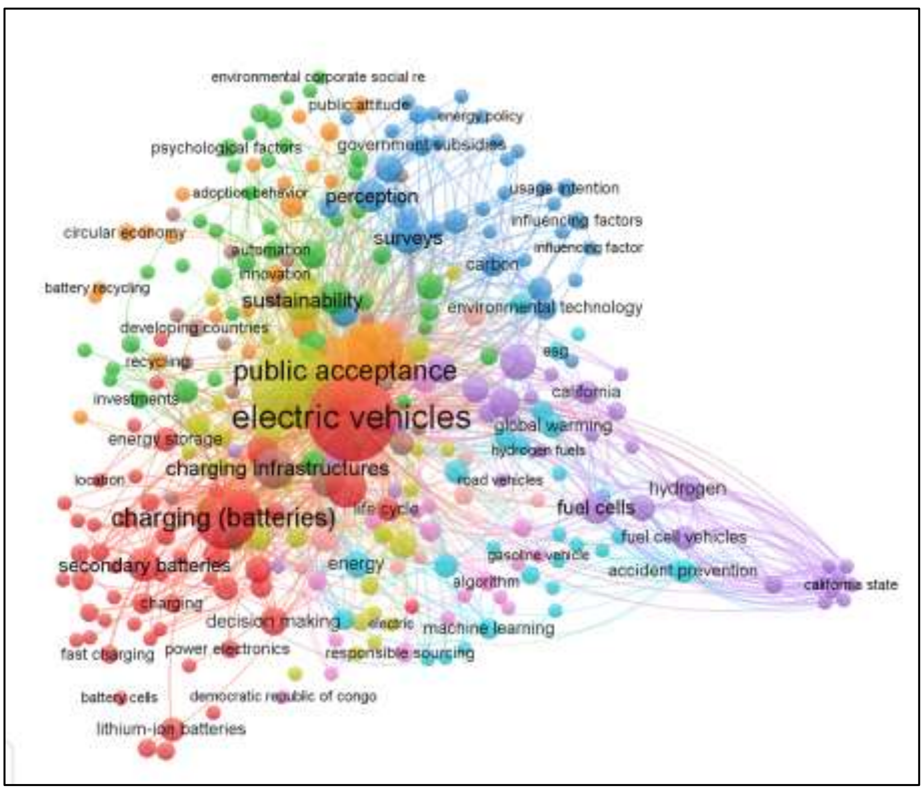

Figure 5. Keyword co-occurrence network in electric vehicle research.

The clusters highlight dominant themes such as electric vehicles, public acceptance, charging infrastructure, and sustainability, alongside emerging topics like fuel cells, circular economy, and machine learning.

4.8 Citation and Co-Citation Analysis

The co-citation network visualization illustrates the structural landscape of scholarly influence within the field of sustainable energy and transport research. The layout reveals a dense, interconnected structure, with journals and sources acting as citation anchors forming discernible thematic concentrations. At the centre of the network, journals such as *Applied Energy*, *Renewable and Sustainable Energy Reviews*, *Energy Policy*, and *Journal of Cleaner Production* emerge as the most frequently co-cited sources. Their large node sizes indicate a high citation frequency, signifying their foundational role in shaping ongoing debates and disseminating core

knowledge in the domain. These sources are well positioned across multiple clusters, reflecting their interdisciplinary relevance in both energy systems and sustainability transitions.
The spatial distribution of nodes shows a clustering effect that suggests the presence of distinct research streams. Journals like *Transportation Research Part D* and *Energy Efficiency* form part of an application-oriented research concentration that integrates environmental assessment, transportation studies, and behavioural analysis. In contrast, journals such as *Environmental Science & Technology* and *Science* are situated closer to scientific inquiry and innovation-based literature, offering strong technical grounding. The presence of multiple color-coded clusters highlights the existence of semi-autonomous research paradigms. Each cluster corresponds to a group of journals that are frequently cited together, indicating thematic similarity, or shared intellectual lineage. The clusters are closely linked, though some peripheral nodes such as those representing niche or emerging journals show weaker integration into the core discourse, suggesting specialized or newly developing areas of inquiry.
The figure also reflects the emergence of interdisciplinary linkages, with journals from engineering, policy, economics, and environmental science increasingly cited in combination. This underscores the growing complexity and convergence of sustainability-focused research, where addressing global challenges demands cross-domain collaboration and knowledge integration.
Overall, the co-citation map offers a compact representation of the field's intellectual backbone, highlighting both the dominant sources and the evolving relationships between key research streams. The configuration reveals a well-structured but dynamic knowledge base with both consolidated domains and areas of fragmentation, providing valuable insights into the evolution and integration of sustainable mobility and energy scholarship.

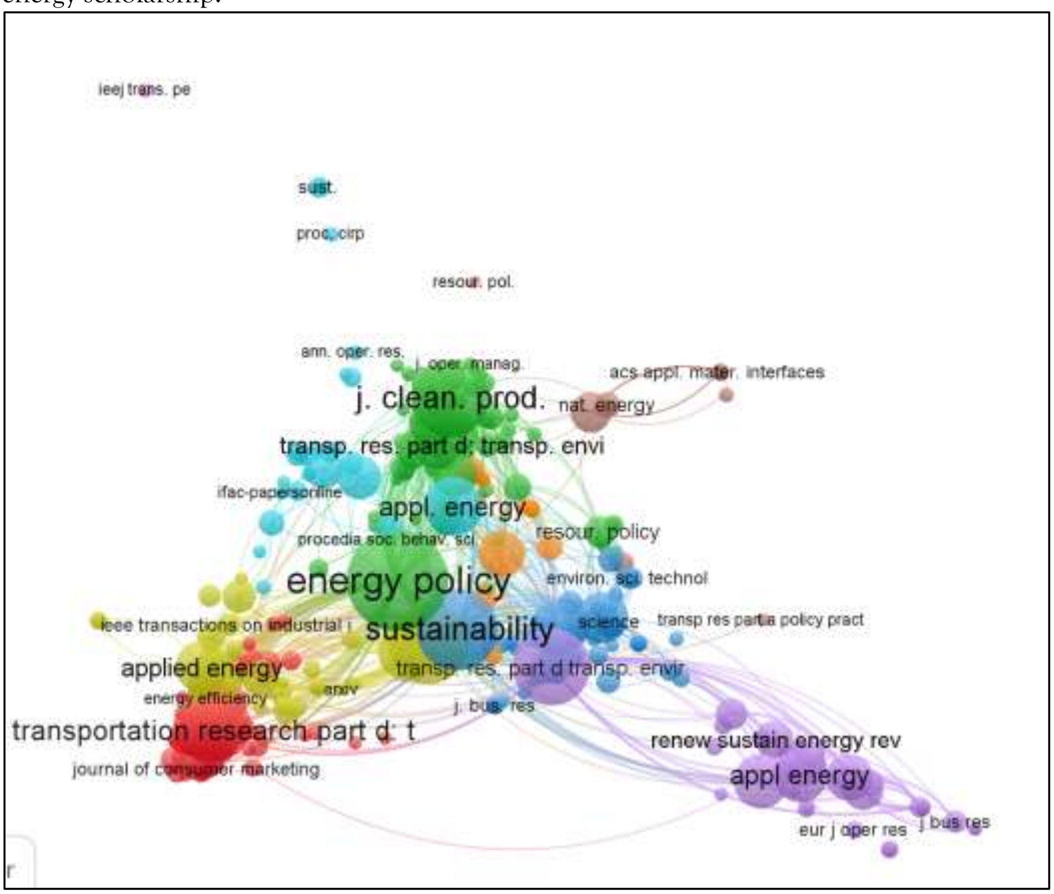

Figure 6. Source co-citation network in electric vehicle research.
The network reveals clusters of influential journals, with *Journal of Cleaner Production*, *Applied Energy*, *Energy Policy*, and *Sustainability* emerging as central knowledge bases shaping the field.

5. DISCUSSION

This discussion interprets the bibliometric results through theoretical, contextual, and policy lenses. Findings are linked to the *Sociotechnical Transitions Theory* and *Innovation Diffusion Theory,* reflecting how scientific knowledge on electric vehicles (EVs), charging infrastructure, and sustainability is organized, disseminated, and evolving. Four key dimensions are explored: thematic insights, knowledge inequalities, theoretical reflections, and methodological contributions.

5.1 Thematic Insights and Research Priorities

The keyword co-occurrence network (Figure 6) reveals four dominant thematic clusters anchored around *electric vehicles*, *public acceptance*, *charging infrastructure*, and *sustainability*. These core concepts demonstrate the multi-dimensional nature of the research field, aligning with the *multi-level perspective (MLP)* of sociotechnical transitions where innovations interact across micro (niche technologies), meso (regimes), and macro (landscape) levels (Geels, 2002).

The dominance of electric vehicles and charging infrastructures in central clusters, supported by high citation counts in articles like *Optimal Fast Charging Station Placing and Sizing* (Sadeghi-Barzani et al., 2014), indicates sustained scholarly interest in technological optimization. Meanwhile, the visibility of terms such as public acceptance, decision-making, and developing countries suggests increasing attention to behavioral and contextual determinants (Albarracín, et al.,2024). *Innovation Diffusion Theory,* which emphasizes the role of perceived attributes, social systems, and communication channels in innovation uptake. Emerging clusters like *machine learning*, *responsible sourcing*, and *battery recycling* suggest a shift toward *data-driven and sustainability-oriented research*, highlighting an inflection point in research priorities where ethical and circular economy considerations intersect with mobility innovations. This expanding thematic frontier offers new opportunities for integrating EV studies with AI, environmental justice, and supply chain ethics.

5.2 Knowledge Production Inequalities and Collaboration Patterns

The analysis of scientific productivity and collaboration patterns reveals significant *asymmetries in knowledge production*, echoing global research disparities commonly documented in bibliometric literature (Arvanitis & Gaillard, 2000; Confraria & Godinho, 2015). As shown in Figure 5 and Tables 3 and 4, leading affiliations such as *RWTH Aachen University*, *University of Michigan*, and *Stanford University* dominate in terms of article output, while *African and other Global South institutions remain peripheral.*

Co-authorship network analysis (Figure 8) further reflects *fragmented collaboration structures,* with strong intra-cluster ties among Global North authors but limited trans-regional integration. This insularity raises concerns about *the transferability of research findings* to developing contexts, particularly where infrastructural and policy conditions differ substantially. Authors such as *Deb S.* and *Hamilton JJ* appear as central nodes in dense collaboration clusters, while isolated nodes suggest under-utilized potential for cross-border collaboration.

These findings underscore the need for *deliberate funding and policy incentives* to support South–South and North–South partnerships. Without such efforts, the knowledge base risks perpetuating epistemic dominance and technological solutions that may be *misaligned with the realities of low-income and informal urban settings.*

5.3 Theoretical Reflections and Fragmentation of Research Paradigms

The co-citation map (Figure 6) reveals distinct paradigmatic clusters, separating EV infrastructure optimization literature from studies on micromobility, behavioral acceptance, and alternative energy technologies. While seminal works like those by Ziefle M., Bekhet H. A., and Tyagi R. form the intellectual backbone of technological and environmental innovation discourse, recent analyses also highlight the role of technological innovations in environmental impact mitigation (Osheyor et al., 2024), though the network structure indicates a lack of cross-citation between technological and sociocultural research silos.

This disciplinary fragmentation suggests a missed opportunity for interdisciplinary synthesis, which is essential for addressing the complex, layered challenges of sustainable urban mobility. From a sociotechnical transitions perspective, this misalignment between technical innovation and societal adoption pathways inhibits system-wide transformation. Integration of innovation diffusion frameworks with mobility and energy transition studies could bridge this gap and guide context-responsive and user-centric innovation.

Furthermore, few studies explicitly theorize *how social justice, governance, or infrastructure equity mediate innovation adoption* in regions like Sub-Saharan Africa, despite keywords such as "Democratic Republic of

Congo" and "developing countries" appearing at the network periphery. This gap warrants deeper theorization on *justice-centered transitions and the role of geopolitical dynamics* in EV supply chains.

5.4 Methodological Contributions of Bibliometrics

This study demonstrates the value of bibliometric techniques as powerful tools for mapping knowledge structures, identifying emerging trends, and uncovering research silos. Co-authorship, keyword co-occurrence, and co-citation analyses offer both macro- and meso-level insights into the intellectual organization of the EV research field. Unlike traditional narrative reviews, this approach provides quantifiable evidence of thematic evolution, collaboration patterns, and institutional influence, supporting strategic research planning and agenda-setting.

However, bibliometric approaches are not without limitations. The reliance on Scopus-indexed publications may exclude valuable regional or grey literature, especially from non-indexed African journals or policy documents. Moreover, citation-based indicators may undervalue emerging scholars or contexts with limited global exposure. As such, bibliometrics should be complemented with qualitative and participatory foresight approaches, particularly when informing inclusive and equitable mobility transitions.

5.5 Policy Implications and Future Funding Directions

Findings from this analysis have direct relevance for transport policy, research funding, and capacity-building. The fragmentation across EV, micromobility, and energy storage domains suggests the need for integrated policy frameworks that bridge urban planning, transport, energy, and digital infrastructure. Furthermore, underrepresentation of Global South actors in both authorship and co-citation networks calls for rebalanced funding mechanisms, such as targeted fellowships, open-access publishing support, and multi-country pilot projects.

At a global level, organizations such as the World Bank, UN-Habitat, and AfDB could prioritize transdisciplinary, South-led research consortia to align innovations with social, environmental, and cultural contexts. National governments must also embed EV adoption strategies within broader climate adaptation and green industrialization agendas.]

6. CONCLUSION AND FUTURE RESEARCH

This bibliometric analysis has illuminated the evolving structure, thematic priorities, and scholarly dynamics within the domain of sustainable electric mobility and low-emission transport systems. The evidence points to a growing research momentum in the field, with increasing scholarly output and citation trends indicating a maturation of interest, particularly in areas related to electric vehicle adoption, battery technologies, charging infrastructure, and public acceptance. Despite this growth, the diffusion of knowledge remains uneven both geographically and thematically. While countries like the United States, Germany, and China dominate the scientific landscape, contributions from the Global South, particularly Sub-Saharan Africa and Latin America, remain underrepresented. This skewed distribution not only signals inequalities in research production capacity but also raises concerns about the global relevance and inclusivity of solutions being developed.

A core insight from the keyword co-occurrence and thematic clustering is the fragmented nature of the discourse. Research remains siloed across sub-domains such as electric vehicles, micromobility, fuel cell development, and sustainable charging systems, with limited interdisciplinary convergence. This thematic disjointedness constrains the field's potential to inform holistic and cross-sectoral policy frameworks. There is an urgent need to integrate transport research with urban planning, energy systems, and behavioral studies to address sustainability in a more comprehensive and context-sensitive manner. Without such integration, policy recommendations risk being technocratic and divorced from socio-political realities.

Furthermore, this study underscores the utility of bibliometric methods in shaping strategic research directions and guiding funding priorities. By mapping influential authors, institutions, and collaboration networks, bibliometrics offers critical visibility into the intellectual structure of the field and highlights areas for greater collaboration, particularly between high-output countries and those with emerging transport challenges.

In terms of practical implications, urban planners and transport policymakers should prioritize cross-sectoral mobility strategies that incorporate technological innovation, citizen behaviour, and environmental impact into a unified decision-making framework. Investment in inclusive research networks that connect scholars from the Global South with global research consortia is essential to ensure more equitable knowledge exchange and policy design. Policymakers must also recognize the strategic importance of digital and infrastructural integration to accelerate low-carbon transitions, especially in urban centres facing rapid motorization and air quality challenges.

Future research should consider expanding bibliometric datasets beyond Scopus and Web of Science to include grey literature, policy reports, and conference proceedings, particularly those from underrepresented regions. Combining bibliometric analysis with qualitative content analysis would further enrich the interpretative depth, revealing not only who is publishing but also what normative assumptions and value frameworks are embedded within the literature. It is especially crucial to focus on emerging contexts such as Africa, Latin America, and South Asia, where rapid urbanization, energy transitions, and climate vulnerability intersect most acutely. Such regionally anchored studies could shed light on context-specific barriers and enablers of sustainable transport adoption, thereby contributing to more globally inclusive knowledge production.

In conclusion, the current trajectory of sustainable mobility research is promising but remains constrained by regional, thematic, and disciplinary fragmentation. A more integrative, equity-oriented, and policy-relevant research agenda fueled by both robust bibliometric tools and inclusive collaboration is needed to guide future mobility transitions in an era of deepening climate and urban challenges.

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