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Optimizing renewable energy: advanced strategies for enhanced efficiency and sustainability

THE CHARGING INFRASTRUCTURE FACTORS THAT INFLUENCE THE COMPETITIVENESS OF THE ELECTRIC MOBILITY SECTOR

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ABSTRACT

The pursuit of improved competitiveness through innovation is increasingly present in the discourse, policies, and strategies of countries. In the context of electric mobility, innovation in electric vehicle charging infrastructure can be considered fundamental to the overall competitiveness of the sector. The objective of this study was to conduct a comprehensive literature review for a structured search and selection of relevant papers that would enable the identification of the main charging infrastructure factors that influence the competitiveness of the electric mobility sector, using the Parsifal[®] platform. As a result, 20 papers were identified, selected, and analysed, addressing partially or entirely factors related to charging infrastructure that impact the sector's development and competitiveness. Categorised into five dimensions, 21 factors were identified (economic, technical, environmental, social, and political), which, when studied together, can support more assertive decision-making regarding investments and guide the development of more effective strategies and public policies for the expansion and consolidation of the electric mobility sector across countries.

Keywords: Charging infrastructure; Electric mobility; Vehicle electrification; EV charging stations; Literature review.

RESUMO

A busca pelo aumento da competitividade por meio da inovação está cada vez mais presente nos discursos, políticas e estratégias dos países. Tratando-se da mobilidade elétrica, a inovação na infraestrutura de recarga de veículos elétricos pode ser apontada como fundamental para o desenvolvimento e competitividade do setor com um todo. O objetivo deste estudo foi conduzir um mapeamento abrangente da literatura para uma busca estruturada e seleção de artigos relevantes que permitissem identificar os principais fatores de infraestrutura de carregamento que influenciam a competitividade do setor de mobilidade elétrica, utilizando a plataforma Parsifal[®]. Como resultado, foi realizada a identificação, seleção e análise de 20 artigos científicos que tratam parcialmente ou integralmente de fatores relacionados a infraestrutura de recarga que influenciam a competitividade do setor. Foram identificados 21 fatores categorizados em cinco dimensões (econômica, técnica, ambiental, social e política) que, ao serem estudados conjuntamente, podem possibilitar a tomada de decisão mais assertiva quanto à investimentos e orientar o desenvolvimento de estratégias e políticas públicas mais efetivas para expansão e consolidação do setor de mobilidade elétrica de diversos países.

Palavras-chave: Infraestrutura de recarga; Mobilidade elétrica; Eletrificação veicular; Eletropostos; Revisão da literatura.



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1 INTRODUCTION

The low air quality, especially in urban centres, climate change, and the growing demand for fossil fuels with finite availability constitute major challenges for contemporary society (SOBCZUK; BORUCKA, 2024). The transportation sector is responsible for a considerable share of these issues, as it generates significant emissions of carbon dioxide (CO₂) and other greenhouse gases (RIBEIRO; MENDES, 2022) and accounts for approximately 27% of global emissions resulting from the combustion of fossil fuels (IEA, 2025).

Electric mobility has become a central element as an alternative for the energy transition, as it employs vehicles that do not emit greenhouse gases during operation and emerges as a promising solution to mitigate carbon emissions (ARAÚJO; ZANIN, 2024). The growing adoption of electric vehicles in different regions highlights the urgent need for sustainable transportation alternatives, reducing reliance on traditional energy sources and fostering an environmentally responsible economy (PAVIĆ; PANDŽIĆ; CAPUDER, 2020). This transformation is not limited to the adoption of new technologies but represents a complex multidimensional process, encompassing economic, social, and urban infrastructure factors, among others (NYKVIST; WHITMARSH, 2008).

The growing demand for electric vehicles has driven new investments, generating economic opportunities across various sectors. Although the macroeconomic impact is not yet highly significant, certain industries are already experiencing the effects of electrification (ULRICH; LEHR, 2020). Electric vehicles accounted for more than 20% of global automobile sales in 2024, with China and the European Union standing out, driven by public policies, subsidies, and infrastructure (IEA, 2025). However, developing countries face distinct challenges in reconciling economic growth, energy security, and environmental preservation (SOBCZUK; BORUCKA, 2024).

Among the key elements for the viability of electric mobility are high-capacity batteries, propulsion systems, and charging infrastructure, which are essential to ensure operational autonomy (CORTI et al., 2024). Particularly, charging infrastructure plays a decisive role in the large-scale adoption of electric vehicles. In developing countries, challenges such as disparities in energy distribution and vast territorial coverage hinder the implementation of this infrastructure, requiring regulatory integration across levels of government and collaboration between the public and private sectors. (FARHADI; TAFRESHI, 2022; CONSONI et al., 2024).

Strengthening the charging infrastructure is essential for the competitiveness of electric mobility and depends on several factors, including the demand for electric vehicles and consumer preferences; public policies and government incentives; the establishment of strategies and targets; technological advances in batteries; and integration with renewable energy sources. Identifying the key factors for the strengthening and expansion of charging infrastructure, understanding how these factors influence the competitiveness of the electric mobility sector, is essential to support targeted investment by companies operating in the field (CONSONI et al., 2024). It can also support other stakeholders in the electric mobility sector (such as governments, development agencies, science and technology institutes, among others) in developing strategies, support policies, and more assertive tools for the sector's expansion and consolidation.



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This paper aims to identify in the literature the main factors of the charging infrastructure that affect the development and competitiveness of the electric mobility sector, as well as identify those that are most frequently mentioned. As a contribution, the results are expected to provide a more comprehensive view of the factors studied by bringing them together in a single study, as well as to enable a better understanding of the necessary investments in charging infrastructure and a more effective direction for strategic actions and public policies by companies and governments, aimed at increasing the competitiveness of the electric mobility sector. It is worth noting that socioeconomic, regional, and country development stage differences, among other specificities of each locality, are not considered in the study, since the focus is to gather all the factors present in the literature, regardless of the specific characteristics of each location.

2 METHODOLOGY

The literature review was structured to organise knowledge with rigorous search, selection, and analysis criteria to ensure greater reliability and comprehensiveness of results throughout the review process, reducing potential biases (VILLALOBOS-ARIAS et al., 2019). The literature review in this research was developed with the support of the Parsifal® platform, which provides methodological assistance throughout the entire review process, in addition to being free to use and offering links to the main academic databases in its digital library. This tool structures its operation into three main phases: planning, execution, and acceptance (utilisation) of the results. Each stage encompasses specific activities that are essential for the proper conduct of the review (SCANNAVINO et al., 2017).

In the planning stage, the essential elements for conducting the literature review were established: the formulation of research questions, the development of the search strategy across databases available on the Internet, the determination of research sources, the creation of the search string, the definition of selection criteria, and the specification of quality assessment criteria for the selected papers. Table 1 presents a detailed overview of each element that comprises the planning stage of the literature review. This phase was conducted entirely in English, including the terms used in the search string.

Table 1 – Items of the literature review Planning Stage

Items	Description
Research Questions	1. How does charging infrastructure influence the competitiveness of the electric mobility sector? 2. What are the main factors of charging infrastructure that influence the competitiveness of the electric mobility sector?
Search Strategy	Keywords: charging infrastructure, competitiveness, electric mobility sector, factor(s); Synonyms: electric charging infrastructure, determinant(s), influence(s), strategy(ies), policy(ies).
Research Sources	Databases*: Google Scholar, IEEE Digital Library, ISI Web of Science, Science@Direct, Scopus.
Search String	("electric mobility sector") AND ("charging infrastructure" OR "electric charging infrastructure") AND ("factor*" OR "determinant*" OR "influence*" OR "polici*" OR "strateg*") AND ("competitiveness")
Selection Criteria	Selection period: 2020–2025



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	Language: English Type: Full papers published in scientific journals Access: Open access
Quality Assessment Criteria	Reading of title and abstract for qualitative evaluation of relevance to the research topic.

*All databases whose links were available in the digital library of the Parsifal® platform were used.

Source: Authors

The execution stage involved the identification of papers according to the strategy outlined in the planning phase, with the import of metadata (in “BibTeX” format) that met the search, selection, and quality assessment criteria. A total of 40 papers were selected, which, after quality evaluation through title and abstract screening, were narrowed down to 12. The third stage began with these papers being downloaded, read in full, and catalogued, highlighting key contributions to the research topic and to answering the formulated research questions.

3 RESULTS AND DISCUSSION

After reading and cataloguing the 12 articles, an additional 8 papers were identified through the bibliographic references cited by these same articles. These papers met the selection criteria adopted in the literature review and had not been retrieved during the initial searches. Due to their relevance and compliance with the selection criteria, they were incorporated into the research, resulting in a total of 20 papers. Appendices A and B present the complete references for each paper in the order in which they were selected.

Based on a thorough review of the selected literature, 21 factors related to charging infrastructure were identified as influencing the competitiveness of the electric mobility sector across the different regions and contexts examined in the studies. These factors were classified into five dimensions (economic, technical, environmental, social, and political) according to the terminology generally used in the analysed works. This classification enables a clearer understanding of the factors, their significance, and their nature.

The selected articles address one or more relevant factors to the research, either partially (addressing the topic tangentially) or fully. Factors directly related to charging infrastructure were identified, as well as others that can be considered indirectly related, thus allowing a comprehensive view of all aspects that should be understood as determinants. All identified factors can be associated with the development and competitiveness of the electric mobility sector.

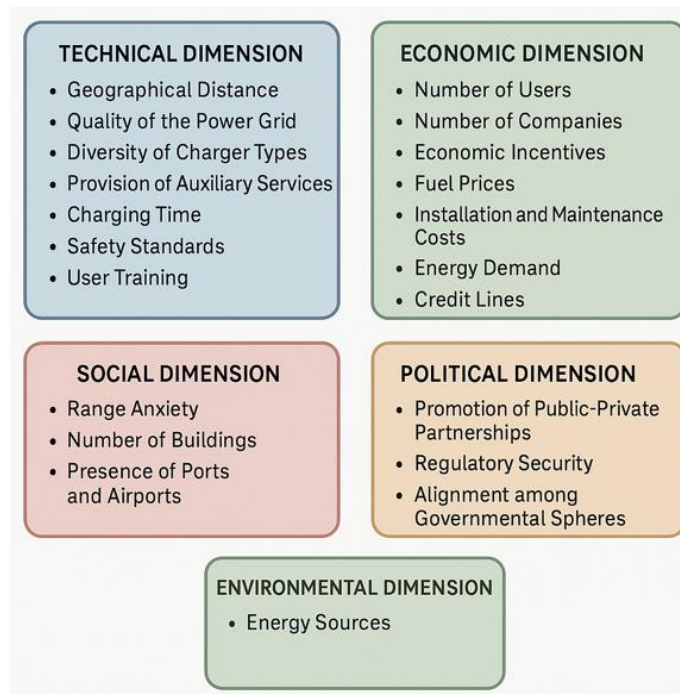
Based on the results obtained, it becomes evident that charging infrastructure is essential to the competitiveness of the electric mobility sector, as it encompasses key technical, economic, environmental, social, and political dimensions, as illustrated in Figure 1. Each dimension encompasses critical variables that influence the feasibility, efficiency, and scalability of infrastructure deployment. Therefore, it becomes clear that charging infrastructure is not merely a technical component, but a multidimensional concept that defines the success and competitiveness of the sector.



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Figure 1 – Charging infrastructure dimensions and factors



Source: Authors

In the technical dimension, the following factors were identified: “Geographical Distance”, “Quality of the Power Grid”, “Diversity of Charger Types”, “Provision of Auxiliary Services”, “Charging Time”, “Safety Standards”, and “User Training”. The efficiency and quality of charging systems have received increasing emphasis in the selected literature, as “Quality of the Power Grid” and “Diversity of Charger Types” were the most frequently mentioned factors, followed by “Geographical Distance” and “Provision of Auxiliary Services” with slightly fewer occurrences. These elements are considered crucial to ensure the reliability, accessibility, and convenience of the charging infrastructure, and their recurrence in the literature indicates a growing concern with the standardization and operational efficiency of the systems (SKALOUMPAKAS et al, 2025; AWAD; DE SANTIS; BAYOUMI, 2025; DAS, 2024; SAXENA et al, 2024; TAVAKOLI et al, 2020; KUMAR et al, 2023; FARINLOYE et al, 2024; JHA; SINGH, 2024; FOSU; ACHINAH, 2024; MAHMUD; MEDHA; ASANUZZAMAN, 2023; PUTRI; ARDI, 2024; KRAEMER et al, 2023; CARVALHO DE SOUSA; CASTAÑEDA-AYARZA, 2022; FABIANEK et al, 2020; PINTO et al, 2020).

In the economic dimension, the following factors were identified: “Number of Users”, “Number of Companies”, “Economic Incentives”, “Fuel Prices”, “Installation and Maintenance Costs”, “Energy Demand”, and “Credit Lines”. The most prominent factor is “Economic Incentives”, as it was the most frequently mentioned in the selected literature. “Installation and Maintenance Costs”, as well as “Fuel Prices”, also stood out in terms of frequency. Thus, the literature appears to indicate that charging infrastructure requires economic incentives from public authorities to be feasible in terms of implementation and operation. This emphasis suggests that, without financial support mechanisms, private investments tend to be limited, compromising the



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expansion of the network. The recurrence of this theme reinforces the idea that incentives are not only desirable but essential to overcome economic barriers (SKALOUMPAKAS et al, 2025; AWAD; DE SANTIS; BAYOUMI, 2025; LIU et al, 2021; OLABI et al, 2022; DAS, 2024; SAXENA et al, 2024; KUMAR et al, 2023; FARINLOYE et al, 2024; JHA; SINGH, 2024; FOSU; ACHINAH, 2024; KRAEMER et al, 2023; CARVALHO DE SOUSA; CASTAÑEDA-AYARZA, 2022; FABIANEK et al, 2020; PINTO et al, 2020).

In the environmental dimension, specifically regarding charging infrastructure, the factor “Energy Sources” was identified as a determining element, since the expansion of infrastructure – especially when associated with renewable sources – contributes to the reduction of greenhouse gas emissions and improves air quality in cities, thereby strengthening the expansion of electric mobility adoption (SKALOUMPAKAS et al, 2025; AWAD; DE SANTIS; BAYOUMI, 2025; JHA; SINGH, 2024; CARVALHO DE SOUSA; CASTAÑEDA-AYARZA, 2022; FABIANEK et al, 2020; PINTO et al, 2020).

In the social dimension, the highlight is the factor “Range Anxiety”, which refers to the concern of electric vehicle users about running out of charge before reaching a charging point. When the charging network is scarce, poorly distributed, or presents operational failures, users tend to feel uncertain about the feasibility of making longer trips. Complementing the social dimension are the factors “Number of Buildings” (houses, apartment complexes, etc.) and the “Presence of Ports and Airports” in the region (SKALOUMPAKAS et al, 2025; AWAD; DE SANTIS; BAYOUMI, 2025; ALDHANHANI et al, 2024; YUVARAJ et al, 2024; SHAHIN et al, 2024; FARINLOYE et al, 2024; JHA; SINGH, 2024; CARVALHO DE SOUSA; CASTAÑEDA-AYARZA, 2022).

In the political dimension, the following factors were identified: “Promotion of Public-Private Partnerships”, “Regulatory Security”, and “Alignment among Governmental Spheres”. The literature highlights the need for “Public-Private Partnerships”, which had the highest number of occurrences. “Alignment among Governmental Spheres” and “Regulatory Security” stand out particularly in studies that address the challenges faced by developing countries. Charging infrastructure is a strategic tool for governments aiming to meet climate goals and foster innovation. The absence of clear guidelines or consistent investments can lead to regulatory uncertainty and limit the growth of electric mobility (AWAD; DE SANTIS; BAYOUMI, 2025; SAXENA et al, 2024; FARINLOYE et al, 2024; JHA; SINGH, 2024; FOSU; ACHINAH, 2024; CARVALHO DE SOUSA; CASTAÑEDA-AYARZA, 2022; PINTO et al, 2020).

4 CONCLUSIONS

This study aimed to identify the various charging infrastructure factors presented in the literature that influence the development and competitiveness of the electric mobility sector, as well as to identify those that are most frequently mentioned. Identifying such factors provides a more comprehensive and integrated view and enables a better understanding of the necessary efforts and investments in charging infrastructure for the strengthening and expansion of the electric mobility sector.

Charging infrastructure plays a central role in the competitiveness of the electric mobility sector, as it directly affects the adoption, operation, and expansion of electric vehicles. A total of 21 factors related to charging infrastructure were identified



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and categorized into five dimensions (technical, economic, environmental, social, and political) offering a comprehensive perspective on the key aspects that should be recognized as determinants of the sector, regardless of socioeconomic conditions, regional characteristics, country development stages, or other local differences.

Some factors were more recurrent in studies and discussions on the topic, standing out in the results presented. In the technical dimension, the quality of the electrical grid stands out as essential to ensure stable and efficient energy supply to charging points, avoiding interruptions and overloads; and the diversity of charger types, which allows for serving different user profiles and vehicle models, expanding access and convenience. In the economic dimension, installation and maintenance costs prove to be impactful on the economic viability of projects, influencing the expansion of the network. Energy sources, in the environmental dimension, also play a strategic role, affecting the attractiveness of electric mobility compared to conventional alternatives. Range anxiety related to electric vehicles, in the social dimension, can be mitigated with a well-distributed and reliable infrastructure. In the political dimension, the highlight is the alignment between governmental spheres and regulatory security, which are crucial as they ensure stability, predictability, and investment incentives. All these interconnected factors contribute to consolidating a favourable environment for the large-scale adoption of electric mobility.

Identifying the key factors of charging infrastructure highlighted in the literature can enable future research aimed at determining which elements should be prioritized or urgently addressed by the various stakeholders directly or indirectly involved in the electric mobility sector. This facilitates the development of investment roadmaps, the establishment of public policies, and the implementation of infrastructure projects. Such analysis contributes to more efficient resource allocation, avoiding fragmented efforts and fostering synergies between public and private initiatives. Moreover, it enables for the anticipation of technical and regulatory bottlenecks, promoting greater predictability for market players and reducing legal uncertainty. Understanding these factors also supports the creation of standards and guidelines that ensure safe and interoperable infrastructure expansion. As a result, it becomes possible to accelerate the energy transition in the transportation sector, ensuring greater consumer adoption and stimulating technological innovation.

As a limitation of the study, it is worth noting the difficulty in identifying, within the analysed works, the determining factors of charging infrastructure in isolation, without interpolation with factors identified as determinants for the adoption and development of electric mobility in general. Many of the factors are common to both infrastructure and electric mobility; however, the focus of this research was to identify those specifically related to charging infrastructure.

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VILLALOBOS-ARIAS, Leonardo et al. *Model-based testing areas, tools and challenges: A tertiary study*. CLEI Electronic Journal, v. 22, n. 1, p. 3: 1-3: 38, 2019.

** The references obtained in the literature review are presented in Appendices A and B.



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APPENDIX A

Table – Articles Selected in the literature review

Nº	Reference
01	SKALOUMPAKAS, P. et al. Optimizing electric vehicle charging station placement in Greek municipalities through multi-criteria decision analysis. <i>Sustainable Energy, Grids and Networks</i> , v. 41, p. 101589, 2025.
02	AWAD, H.; DE SANTIS, M.; BAYOUMI, E. H. Electric Vehicle Adoption in Egypt: A Review of Feasibility, Challenges, and Policy Directions. <i>World Electric Vehicle Journal</i> , v. 16, n. 8, p. 423, 2025.
03	DAS, S. Enabling role of policies to make public charging infrastructure development viable in an Indian city: A modelling-based analysis. <i>Transport Economics and Management</i> , v. 2, p. 286-301, 2024.
04	SAXENA, N. K. et al. Economic benefits of DSTATCOM for ancillary services in commercial charging stations: Marginal occupancy analysis. <i>Ain Shams Engineering Journal</i> , v. 15, n. 12, p. 103029, 2024.
05	FARINLOYE, T. et al. Driving the electric vehicle agenda in Nigeria: The challenges, prospects and opportunities. <i>Transportation Research Part D: Transport and Environment</i> , v. 130, p. 104182, 2024.
06	JHA, R.; SINGH, M. K. Electric mobility adoption in India–Policy & initiatives to promote E-Mobility in Jharkhand. <i>International Management Review</i> , v. 20, n. 1, p. 63-74, 2024.
07	FOSU, G. O.; ACHINAH, S. Exploring the prospects and challenges of electric vehicle adoption: paving the way for a sustainable future in transportation. Available at <i>SSRN 4867809</i> , 2024.
08	PUTRI, S. A.; ARDI, R. Critical Success Factors of Electric Mobility Transition in Indonesia: A DEMATEL-Based ANP Approach. <i>TEM Journal</i> , v. 13, n. 3, p. 2076, 2024.
09	KRAEMER, R. A. S. et al. Regulatory Challenges in the Electromobility Sector: An Analysis of Electric Buses in Brazil. <i>Energies</i> , v. 16, n. 8, p. 3510, 2023.
10	CARVALHO DE SOUSA, G.; CASTAÑEDA-AYARZA, J. A. PESTEL analysis and the macro-environmental factors that influence the development of the electric and hybrid vehicles industry in Brazil. <i>Case Studies on Transport Policy</i> , v. 10, n. 1, p. 686-699, 2022.
11	FABIANEK, P. et al. Green and regional? A multi-criteria assessment framework for the provision of green electricity for electric vehicles in Germany. <i>Transportation Research Part D: Transport and Environment</i> , v. 87, p. 102504, 2020.
12	PINTO, B. et al. Fleet transition from combustion to electric vehicles: A case study in a Portuguese business campus. <i>Energies</i> , v. 13, n. 5, p. 1267, 2020.

Source: Authors

APPENDIX B

Table – Subsequently incorporated papers

Nº	Reference
01	LIU, Z. et al. Comparing total cost of ownership of battery electric vehicles and internal combustion engine vehicles. <i>Energy Policy</i> , v. 158, p. 112564, 2021.
02	OLABI, A. G. et al. Battery electric vehicles: Progress, power electronic converters, strength (S), weakness (W), opportunity (O), and threats (T). <i>International Journal of Thermofluids</i> , v. 16, p. 100212, 2022.
03	KUMAR, M. et al. Comprehensive review of electric vehicle technology and its impacts: detailed investigation of charging infrastructure, power management, and control techniques. <i>Applied Sciences</i> , v. 13, n. 15, p. 8919, 2023.
04	TAVAKOLI, A. et al. Impacts of grid integration of solar PV and electric vehicle on grid stability, power quality and energy economics: A review. <i>IET Energy Systems Integration</i> , v. 2, n. 3, p. 243-260, 2020.
05	MAHMUD, I.; MEDHA, M. B.; HASANUZZAMAN, M. Global challenges of electric vehicle charging systems and its future prospects: A review. <i>Research in Transportation Business & Management</i> , v. 49, p. 101011, 2023.
06	ALDHANHANI, T. et al. Future trends in smart green iov: Vehicle-to-everything in the era of electric vehicles. <i>IEEE Open Journal of Vehicular Technology</i> , v. 5, p. 278-297, 2024.
07	YUVARAJ, T. et al. A comprehensive review and analysis of the allocation of electric vehicle charging stations in distribution networks. <i>IEEE access</i> , v. 12, p. 5404-5461, 2024.
08	SHAHIN, A. et al. A comprehensive analysis: Integrating renewable energy sources with wire/wireless EV charging systems for green mobility. <i>IEEE Access</i> , 2024.

Source: Authors