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A Systematic Literature Review of Risk Assessment Methodologies for Electric Bus Infrastructure

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Abstract

The transition to electric bus infrastructure represents a significant advancement in addressing environmental challenges and promoting sustainable urban mobility. However, the development and operation of this infrastructure face various technical, economic, environmental, and social risks. This study aims to identify, analyze, and evaluate risk assessment methodologies employed in this context through a systematic literature review (SLR) approach. We reviewed 22 selected studies published between 2015 and 2025, categorizing the risk assessment approaches into several groups, including probabilistic simulation (e.g., Monte Carlo), Conditional Value-at-Risk (CVaR), fuzzy logic, Multicriteria Decision-Making (MCDM), integrated Risk Assessment Framework (RAF), and social life cycle assessment (S-LCA). Our findings indicate that the majority of studies focused primarily on technical and financial risks, while social and environmental dimensions received comparatively less attention. Furthermore, several general limitations were identified, such as the lack of geographical diversity in studies, insufficient emphasis on cybersecurity, and the absence of practical testing. This study concludes that the development of a more comprehensive, adaptive, and interdisciplinary risk assessment model is urgently needed to facilitate the implementation of safe, resilient, and sustainable electric bus infrastructure on a global scale.

Keywords
Risk Assessment, Methodologies, Infrastructure, Prisma, Electric Bus.
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1. Introduction
Electric bus infrastructure represents a pivotal solution in mitigating air pollution, reducing greenhouse gas emissions, and addressing the increasingly urgent challenges posed by climate change. As an integral component of a more

sustainable public transportation system, electric buses offer numerous economic and ecological advantages. Notably, they contribute to the reduction of CO_2 emissions, thereby directly enhancing air quality and decreasing reliance on fossil fuels. With growing awareness of the importance of energy sustainability and minimizing environmental impact, electric buses are emerging as a leading alternative in urban transportation systems. Consequently, it is imperative for cities and countries worldwide to transition to electric transportation systems as a strategy for decarbonization (Gupta et al. 2019).

Beyond the environmental advantages, the infrastructure for electric buses can also positively influence the economy by generating employment opportunities in sectors such as renewable energy, charging, and the manufacturing of the buses themselves. For instance, advanced charging infrastructure facilitates more efficient energy management and supports the transition to renewable energy sources. Electric buses have a lot of potential to improve air quality and spur economic growth, but building and running their infrastructure is fraught with difficulties. A primary challenge involves the assessment and mitigation of risks associated with various infrastructure components, including charging stations, electricity distribution networks, and vehicle battery performance. The design of charging infrastructure for electric buses must account for various technical risks, such as battery damage, charging system reliability, and operational risks related to physical damage to the vehicle or disruptions in the distribution network (Li et al. 2020).

Several factors must be considered regarding economic risk, including the high costs associated with building and maintaining the infrastructure. The importance of risk assessment is therefore not only related to operational reliability but also to energy security and long-term economic sustainability. This is the foundation for the need for various risk assessment methodologies to be applied to ensure that electric bus-based transportation systems will be able to operate safely, efficiently, and sustainably in the long term (Zare and Banisalam 2020).

1.1 Objectives

The primary aim of the systematic literature review (SLR) is to identify, analyze, and evaluate the diverse risk assessment methodologies applied to electric bus infrastructure. This review seeks to offer a comprehensive overview of the various approaches employed by researchers and practitioners in assessing and managing risks associated with electric bus infrastructure, encompassing technical, economic, and environmental dimensions. The central focus of this study is to address several significant research questions.

1. What methodologies for risk assessment have been employed in the development of electric bus infrastructure?
2. What are the advantages and disadvantages associated with each methodology employed?
3. How has the research trend in risk assessment evolved in recent years, and to what extent have these methodologies integrated various relevant perspectives?
4. What are the current gaps in research, and how might these gaps present opportunities for future scholarly inquiry?

Through an examination of current methodologies and challenges in risk assessment, this research aims to contribute to the advancement of more effective risk management strategies for the future implementation of electric bus infrastructure. It is anticipated that the findings of this study will be instrumental for policymakers, engineers, and infrastructure managers in designing and operating transportation systems that are safer, more efficient, and sustainable.

2. Literature Review

Recent progress in electric vehicle (EV) infrastructure has led to a variety of risk assessment studies utilizing methods like Monte Carlo simulation (Yang et al., 2016; Duarte and Szpytko, 2020), probabilistic load flow (Zhuang et al., 2025), CVaR-based stochastic models (Afzali et al., 2021; Ahmadi Jirdehi et al., 2022; Almeida et al., 2022), and hybrid techniques that combine fuzzy logic with multi-criteria decision-making (Zhang et al., 2019; Liu and Wei, 2018). These methodologies evaluate technical and economic risks, including transformer overloading (Palomino and Parvania, 2020), grid instability, and operational inefficiencies due to uncoordinated EV charging. Some research also focuses on reducing system-level risks through integrated energy management strategies (Leite et al., 2023; Almeida et al., 2024). Although these methods offer valuable insights, they often rely on historical data or simulation assumptions, which might restrict their adaptability to real-world changes and fast-paced technological advancements. Beyond technical aspects, recent studies have examined broader risks, such as those related to policy, market, and construction uncertainties. For example, Zhang et al. (2019) and Mousavi et al. (2023) identified risks in public-private partnership (PPP) projects, including cost overruns, contractor issues, and policy changes. Research by Liu and Wei (2018) and Li et al. (2020) emphasized the importance of legal, financial, and operational risks in EV charging infrastructure. However, the use of predefined evaluation criteria and a narrow geographic focus has raised concerns about the generalizability and applicability of these studies across different contexts. Additionally, security-related research, such as that by Shirvani et al. (2023; 2024), underscores the growing significance of cybersecurity in EV infrastructure, particularly in terms of data protection, system vulnerabilities, and real-time monitoring of connected systems.

Risk assessments that focus on environmental and social aspects are becoming increasingly popular. Sánchez et al. (2024) introduced frameworks for social life cycle assessments (S-LCA) that consider gender, while Haces-Fernandez and Sharma (2023) utilized GIS tools to assess spatial risks associated with the placement of EV charging stations. Al Wahedi and Bicer (2024) conducted a thorough analysis of safety and environmental risks related to hydrogen- and ammonia-based EV charging systems. Additionally, Hamzeh et al. (2016) and Hajeforosh et al. (2022) explored operational risks linked to the grid under extreme load conditions. These studies highlight the importance of developing integrated frameworks that combine technical, environmental, and social considerations.

In conclusion, while existing models offer significant insights, numerous studies still fall short of validation through practical case studies. For instance, the majority depend on theoretical simulations or limited expert opinions (Ranganathan and Aggarwal, 2020; Sarkis-Onofre et al., 2021). Additionally, the scalability and long-term adaptability of techniques like CVaR (Almeida et al., 2022; Ahmadi Jirdehi et al., 2022) and AI-based forecasting (Leite et al., 2023) have yet to undergo thorough testing across diverse geographic and climatic settings. Overcoming these limitations with empirical research and comprehensive stakeholder involvement can aid in developing resilient, inclusive, and sustainable EV infrastructure systems.

3. Methods

This study utilized a systematic review design to integrate findings from multiple primary studies (Ranganathan and Agarwal 2020). This study was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Sarkis et al. 2021). The subsequent section delineates the study's background and objectives, followed by a comprehensive methodology that details the extensive literature search strategy employed across various databases. It also specifies the inclusion and exclusion criteria applied to identify pertinent studies for the review.

3.1 Search Strategy

A comprehensive search was performed across three prominent electronic databases, including Scopus, for this systematic literature review. These platforms were selected for their extensive coverage of both interdisciplinary and specialized fields. To ensure the capture of all relevant studies, the search strategy employed a combination of keywords and Boolean operators. The specific keywords utilized in the search were:. Keywords used: "risk assessment" OR "risk analysis" OR "hazard identification" OR "risk management" AND "infrastructure" OR "charging station" OR "battery swapping station" OR "bus depot" OR "smart grid" OR "dedicated lanes" OR "payment system" OR "regulatory incentives" OR "bus systems" AND “electric vehicle” OR "electric bus." The search strategy was designed to encompass a wide range of publications addressing various methodologies in safety risk assessment and analysis, specifically focusing on infrastructure electric vehicles. We conducted the search without time restrictions and limited it to English-language documents to achieve a comprehensive review of relevant literature.

3.2 Inclusion and Exclusion Criteria

The inclusion criteria for studies were as follows: English-language publications, those published within the past ten years (2015-2025), Full texts of studies in English, Not duplicate papers, Studies that are about risk assessment of electric bus infrastructure, the document types used are articles, using a clear method. We exclude studies that tackle topics beyond the direct safety risks associated with electric bus infrastructure. This exclusion category encompasses papers that discuss the broader EV ecosystem without a specific focus on infrastructure, electric bus-related issues, or driver safety factors. Additionally, we exclude studies that only provide a general overview of electric bus infrastructure without exploring risk assessment aspects, as well as those that lack transparency in their methods and serve only industrial commercialization. These criteria help refine the selection process, ensuring the inclusion of studies closely related to evaluating the safety of EV infrastructure.

3.3 Data Extraction and Synthesis
A PRISMA flowchart illustrates the stages of identification, screening, eligibility, and inclusion of articles in the selection process for studies. The results section explains the main findings from the chosen studies, comparing current risk assessment methods and looking at their pros and cons. The discussion contextualizes the review's findings within the existing literature, identifies knowledge gaps, and proposes directions for future research. The conclusion encapsulates the review's main contributions, addressing the literature gap in safety risk assessment for electric vehicles.

4. Data Collection
Our search strategy initially identified 222 articles from three Scopus databases, as depicted in Figure 1.

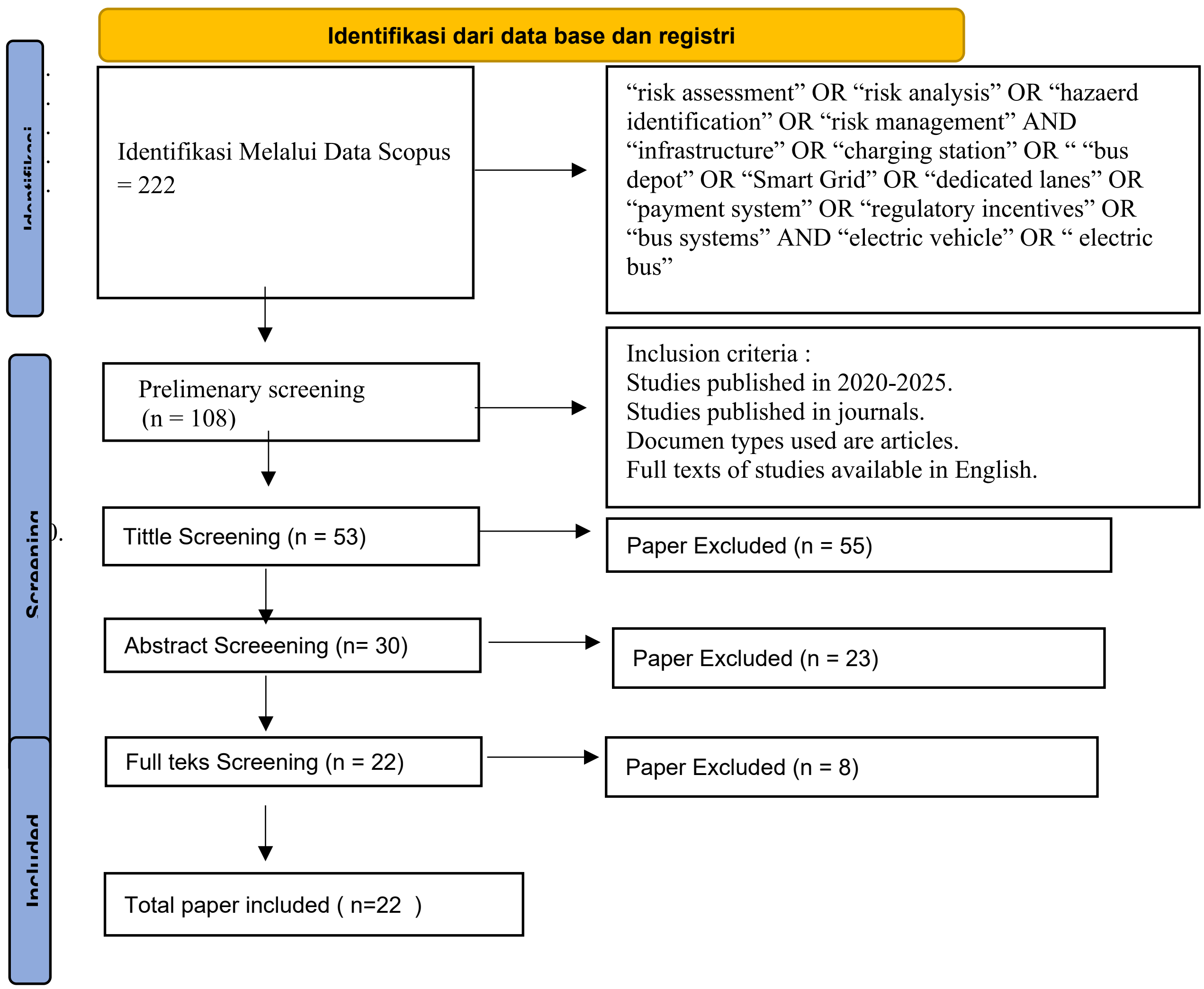

Figure 1. Flowchart depicting the methodology employed in the selection process; PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)

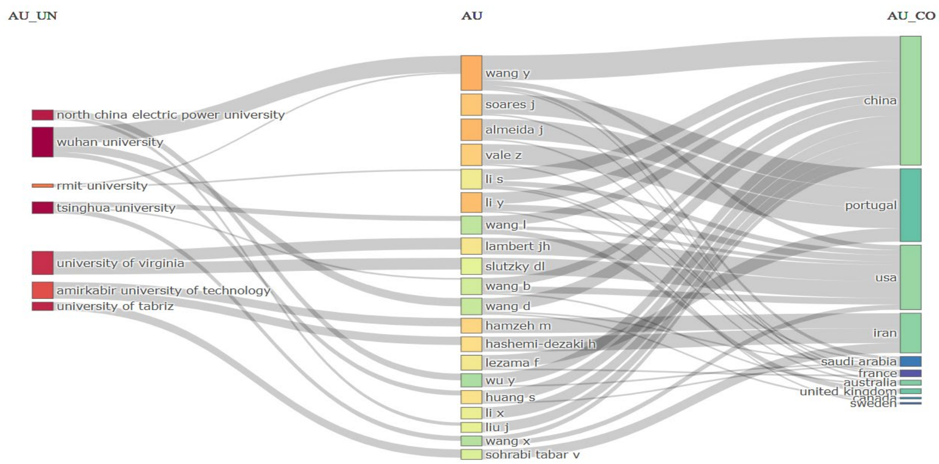

Figure 2. Three Field Plot

The three-field plot illustrates the relationships between author affiliations (AU_UN), individual authors (AU), and their corresponding countries (AU_CO), offering an in-depth look at institutional and geographical contributions to the research domain (Figure 2). The visualization reveals that China is the most dominant contributor, with several prolific authors such as Wang Y, Li S, and Li Y affiliated with major institutions like North China Electric Power University and Wuhan University. In addition to China, other countries such as Portugal, Iran, and the United States also show notable participation, albeit to a lesser extent. Prominent institutions such as the University of Virginia (USA), Amirkabir University of Technology (Iran), and RMIT University (Australia) also contribute through affiliated researchers. The connections mapped across institutions and countries indicate the presence of international collaboration, although the research landscape remains heavily concentrated in East Asia, particularly China.

5. Results and Discussion

5.1. Result

5.1.1 Risk Assessment Methodologies

A comprehensive analysis of 25 studies on electric vehicle infrastructure, including Electric Vehicle Charging Infrastructure, Smart Grids, and Power Distribution Systems, reveals a diverse range of risk assessment methodologies employed across these studies. These methodologies are categorized into several distinct groups. Over 40% of the studies, such as those by Jun Yang et al., Palomino & Parvania, and Duarte et al., utilize probabilistic simulation and Monte Carlo methods, which are particularly effective in addressing uncertainties related to network load, photovoltaic (PV) integration, and electric vehicle (EV) charging demand. Conditional Value-at-Risk (CVaR) is employed in research by Afzali et al., Ahmadi Jirdehi, and Almeida et al. to optimize energy management and evaluate financial and technical risks in grid or microgrid systems. Fuzzy Logic and Multi-Criteria Decision Making (MCDM), particularly through AHP and DEMATEL, are applied in studies such as those by Zhang et al. and Shabbiruddin et al. to manage qualitative data and expert opinions, especially in Public-Private Partnership (PPP) projects and project management risks. A Risk Assessment Framework (RAF), which integrates multiple risk assessment techniques, is utilized in Al Wahedi & Bicer (2024), employing methods such as FMEA, HAZOP, and QRA for a comprehensive analysis of safety, health, and environmental risks in EV charging stations. Additionally, Social Life Cycle Assessment (S-LCA) is used in Sánchez et al.'s study to evaluate the social risks associated with the production and end-of-life stages of EV batteries, while cybersecurity risk models like STRIDE and NIST are highlighted in Shirvani et al.'s study for managing cybersecurity risks in EV systems and charging stations.

The assessment of these methodologies is predicated on three principal criteria: accuracy in risk identification, their contribution to mitigation efforts, and their support for decision-making processes. Monte Carlo simulation and power flow models are particularly adept at identifying and evaluating technical risks, such as overload, transformer aging, and voltage instability. For example, the study by Palomino & Parvania (2020) demonstrates that these techniques can effectively quantify risks associated with transformer lifespan and failure. Conditional Value at Risk (CVaR) and stochastic optimization methods have been shown to facilitate risk-averse decision-making strategies. According to Ahmadi Jirdehi (2022), these methods enhance system stability and reduce economic losses. Fuzzy Logic and Multi-Criteria Decision Making (MCDM) methods, including Decision-Making Trial and Evaluation Laboratory (DEMATEL) and Analytic Hierarchy Process (AHP), are crucial for prioritizing risks and aiding decision-making in contexts of uncertain or ambiguous data, particularly in project risk assessment. Failure Mode and Effects Analysis (FMEA), as employed by Al Wahedi & Bicer (2024), effectively identifies potential failures and evaluates their impact, such as motor and power failures in electric vehicle systems, while also providing strategies for mitigating safety risks at electric vehicle charging stations. Cybersecurity frameworks like STRIDE and the National Institute of Standards and Technology (NIST) are particularly effective in detecting vulnerabilities within electric vehicle systems and offering structured approaches to mitigate those risks. Furthermore, Social Life Cycle Assessment (S-LCA) has proven effective in evaluating the social impact of electric vehicle battery production and recycling, raising awareness of gender equality and labor rights within the supply chain.

In conclusion, the risk assessment methodologies utilized in these studies are specifically tailored to their respective contexts, encompassing technical, economic, environmental, and social dimensions. Quantitative methods, such as Monte Carlo and Conditional Value at Risk (CVaR), are particularly effective for technical and financial evaluations. In contrast, qualitative approaches, including Fuzzy Analytic Hierarchy Process (AHP) and Decision-Making Trial and Evaluation Laboratory (DEMATEL), are more suitable for scenarios characterized by significant social or policy uncertainties. The Risk Assessment Framework (RAF), which integrates methods such as Failure Mode and Effects Analysis (FMEA) and Hazard and Operability Study (HAZOP), provides a more comprehensive approach to managing complex risks. The efficacy of each method is dependent on its application; however, the most robust strategy involves a combination of historical data, simulation techniques, and expert insights to ensure a comprehensive and well-rounded risk assessment process.

5.1.2 Advantages and Disadvantages of methodology

This section examines the benefits and limitations of various risk assessment methodologies employed in the context of electric vehicle infrastructure (Table 1).

Table 1. Advantages and Disadvantages of methodology

Methodology	Advantages	Limitations	Example References
Monte Carlo / Markov Chain	- Handles uncertainty through probabilistic modeling.- Suitable for complex, dynamic systems (e.g., power distribution, reliability).- Provides probability distributions rather than single-point estimates.	- Requires large data sets and high computational effort.- Results depend heavily on assumptions about probability distributions.- Less effective for qualitative or social/environmental risks.	Duarte & Szpytko (2020) [14]Hamzeh et al. (2016) [15]
CVaR (Conditional Value-at-Risk)	- Effective for analyzing extreme financial risks.- Integrates well into economic decision-making and optimization models.- Quantifies tail risk beyond mean outcomes.	- Focused mainly on economic risk, weak for social or environmental dimensions.- Results can be hard to interpret for non-technical stakeholders.- Lacks causal modeling of risk interdependencies.	Almeida et al. (2022) [20]Almeida et al. (2024) [23]
Fuzzy MCDM (AHP, TOPSIS, DEMATEL)	- Capable of integrating multiple risk dimensions (technical, economic, environmental, social).- Suitable for expert-based and qualitative assessments.- Transparent weighting and ranking process.	- Sensitive to subjective bias in criteria weighting.- Not dynamic; struggles to model time-varying risks.- Interdependencies among risks may not be fully captured.	Liu & Wei (2018) [13]Zhang et al. (2019) [11]Zhang et al. (2024) [12]
Hesitant / Wiggly Fuzzy FMEA	- Strong in failure mode analysis and technical risk prioritization.- Can handle expert uncertainty and	- Subjective membership function definitions.- Limited integration of economic, social, or environmental	Zhang et al. (2024) [12]

	imprecise data.- Flexible for different technical systems.	risks.- Validation of results against real data can be challenging.	
S-LCA (Social Life Cycle Assessment)	- Focuses on social risks and impacts (e.g., labor rights, gender, community).- Useful for full life-cycle risk identification.- Highlights non-technical risks often overlooked.	- Data availability for social indicators is often limited.- Weak for technical or economic risk modeling.- Quantification and comparison of social risks can be difficult.	Sánchez et al. (2024) [26]
Integrated Risk Assessment Framework (RAF)	- Can holistically cover technical, economic, environmental, and social risks.- Highly customizable for specific projects or regions.- Supports multi-stakeholder collaboration.	- Complex to design and implement.- Requires interdisciplinary expertise.- Standardization across projects can be difficult.	Haces-Fernandez & Sharma (2023) [16]Mousavi et al. (2023) [18]

Each methodology possesses its own set of strengths and weaknesses, which should be meticulously considered when selecting the most appropriate method for risk assessment in electric bus infrastructure.

5.1.3 Trend and integrated

Figure 3 depicts the progression of significant research terms associated with electric vehicles and energy systems from 2015 to 2025. It underscores a marked increase in academic focus on subjects like “charging station,” “risk assessment,” “risk analysis,” and “vehicle-to-grid” integration, especially between 2020 and 2023. More recent terms such as “renewable energies,” “alternative energy,” and “optimization” have also risen in prominence, reflecting a shift towards sustainable and efficient energy solutions. Earlier topics like “plug-in hybrid vehicles” and “incentive” reached their peak before 2020 and have since experienced a decline in attention. The rise in the frequency and diversity of risk-related terms indicates a growing concern for reliability, safety, and uncertainty management within EV infrastructure. This temporal distribution provides helpful details about the evolving research interests and emerging challenges in the field.

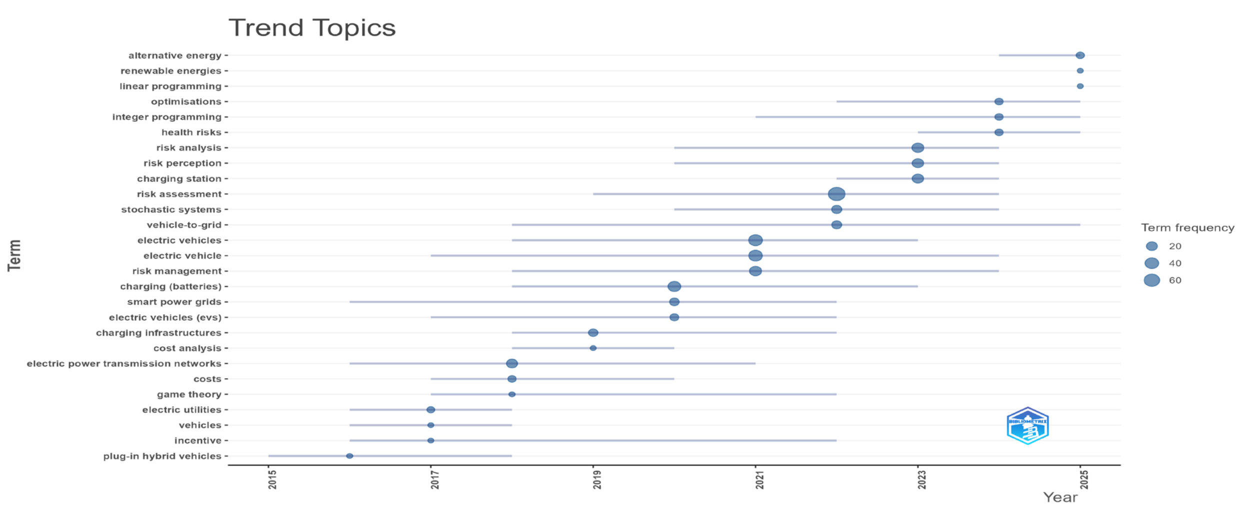

Figure 3. Trend Topic

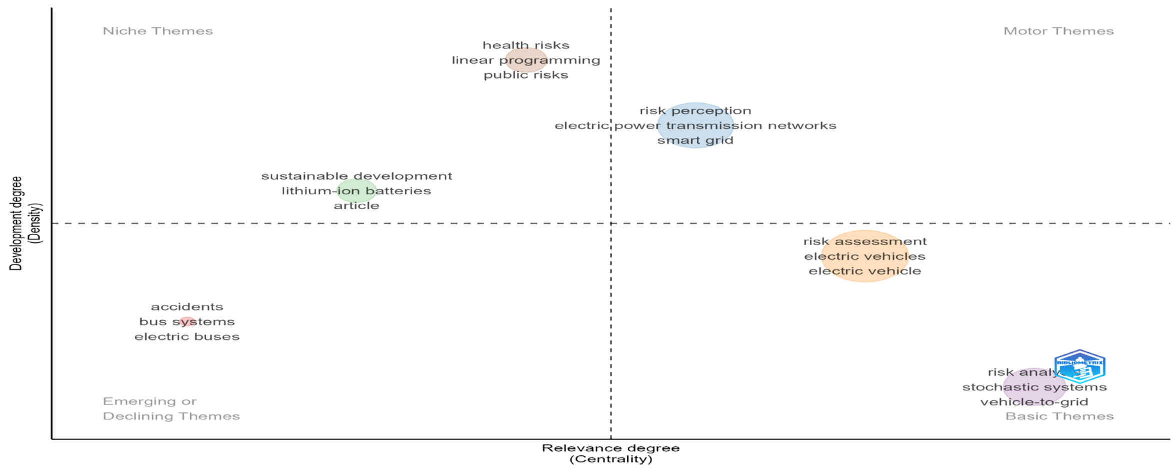

Figure 4. Thematic Map

The thematic map shows where different research topics about electric vehicles and energy systems are placed based on two main factors: how developed they are (density) and how important they are (centrality) (Figure 4). Themes like risk analysis, stochastic systems, and vehicle-to-grid are in the lower-right quadrant (Basic Themes), highlighting their significant relevance to the field while also indicating a need for further conceptual and methodological advancement. Conversely, risk assessment, electric vehicles, and electric vehicle are found in the upper-right quadrant (Motor Themes), denoting that they are not only central but also well-developed, serving as key drivers in this research area. Themes such as risk perception, smart grids, and power transmission networks are categorized as niche themes, meaning they are well-developed internally but have limited external connections, often pertinent within specific or specialized research communities. Meanwhile, sustainable development and lithium-ion batteries are positioned near the center of the map, suggesting they are transitional themes with the potential to evolve into either motor or basic themes depending on future research directions. On the other hand, themes like accidents, bus systems, and electric buses are located in the lower-left quadrant (Emerging or Declining Themes), indicating that these topics either exhibit declining scholarly interest or are still in the early stages of academic exploration. This thematic structure provides helpful details about the shifting priorities and potential future paths in the research landscape of transport electrification and energy risk management (Table 2).

Table 2. Comparison of Risk Assessment Methodologies and Their Integration of Technical, Economic, Environmental, and Social Perspectives

Methodology	Technical & Operational	Economic	Environmental	Social	Integration Level
Monte Carlo / Markov Chain	Strong (detailed simulation, reliability, system failure analysis)	Limited (indirectly through cost of technical failure)	Not directly addressed	Not directly addressed	**Low (focused on technical-operational risks)**
CVaR (Conditional Value-at-Risk)	Limited (indirectly via cost impacts of failures)	Strong (focus on financial and extreme economic risk)	Not directly addressed	Not directly addressed	**Low (focused on economic risks)**
Fuzzy MCDM (AHP, TOPSIS, DEMATEL)	Strong (can include technical-operational criteria)	Strong (able to consider cost, investment)	Medium (depends on criteria design)	Medium (can include if designed)	**Medium-High (flexible, depends on criteria)**
Hesitant / Normal Wiggly Fuzzy FMEA	Strong (failure mode analysis)	Medium (if cost is part of risk priority)	Rarely applied	Rarely applied	**Medium (focused on technical, can be expanded)**
Social Life Cycle Assessment	Not directly addressed	Not directly addressed	Medium (via LCA integration)	Strong (focus on social issues: workers,	**Medium (social-environmental focus)**

				gender, community)	
Integrated Risk Assessment Framework (RAF)	Strong (can integrate technical-operational aspects)	Strong	Medium (depends on design)	Medium (few RAFs cover social aspects deeply)	**High (potential for holistic integration)**

5.1.4. Research Gap

Current research on the risk assessment of electric vehicle (EV) infrastructure highlights several significant shortcomings. Firstly, many studies focus on technical, economic, or environmental risks in isolation, lacking comprehensive frameworks that integrate these risks and their interconnections. Secondly, social and environmental risks, such as community impacts, inequality, and employment effects, are often excluded from risk models, even though they are becoming increasingly important. Thirdly, the research predominantly targets developed regions, overlooking the specific challenges faced by developing countries, rural areas, and tropical climates, as well as the impact of varying energy policies. Fourthly, there are methodological challenges in addressing long-term uncertainties, as numerous studies depend on static models that do not account for technological and policy shifts. Fifthly, cybersecurity risks associated with EV infrastructure are not thoroughly examined, despite the growing digital integration of EV systems. Sixth, small- and medium-sized infrastructure projects—which are more relevant to areas with limited resources—are not given enough attention. Last but not least, the majority of the research in the field is still based on theoretical models and simulations, leading to a lack of empirical validation and real-world case studies. Bridging these gaps is key to creating more resilient, inclusive, and secure EV infrastructure systems.

5.2 Discussion

5.2.1 Interpretasi Temuan Utama

Recent studies on electric bus infrastructure have pointed out different ways to assess risks, including methods like Monte Carlo simulations, Conditional Value-at-Risk (CVaR), Fuzzy Logic, Multi-Criteria Decision Making (MCDM), Risk Assessment Frameworks (RAF), and Social Life Cycle Assessment (S-LCA). Each of these techniques comes with its own unique advantages and drawbacks. While much of the existing literature has concentrated on technical and economic risks—such as network overload, transformer aging, and uncertainties in charging demand—there is a growing emphasis on social factors, particularly through the application of S-LCA. Many studies have shown that using different methods together, like combining Failure Mode and Effects Analysis (FMEA), Hazard and Operability Study (HAZOP), and Quantitative Risk Assessment (QRA) in a Risk Assessment Framework (RAF), can lead to better evaluations. However, the effectiveness of these methods is largely contingent upon the availability and quality of historical data. These findings suggest that there is a more holistic and integrated approach to risk assessment that encompasses technical, economic, environmental, and social dimensions. Such an approach is essential for enhancing the robustness and applicability of risk management strategies in the planning and operation of electric bus infrastructure.

5.2.2 Critique of previous studies.

The critique of existing literature on electric vehicle (EV) infrastructure risk assessment reveals several significant limitations. Many studies mainly use numbers and models like Monte Carlo simulations, CVaR, and fuzzy logic to look at technical and financial risks, but they often overlook important social and political uncertainties that are crucial for long-term sustainability. Furthermore, the dependence on limited historical data compromises the capacity of these models to accurately predict future scenarios influenced by rapid technological advancements and societal transformations. Although methodologies like MCDM and Fuzzy Logic are valuable for managing ambiguity, they frequently rely on subjective expert judgment, which may introduce bias and diminish objectivity. Additionally, there is a conspicuous gap in practical validation, as most studies are simulation-based with minimal evidence of field testing or real-world application. Lastly, despite the growing digitalization of EV systems, cybersecurity remains an insufficiently explored domain, with current models lacking robust mechanisms to evaluate and mitigate IT-related risks. These limitations highlight the necessity for more integrative, empirical, and multidimensional research approaches in future investigations.

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5.2.3 Theoretical and Practical Implication

The theoretical implications of this study underscore the necessity of advancing risk assessment models toward a more comprehensive and integrated framework, particularly within the context of electric vehicle (EV) infrastructure. The study emphasizes the importance of expanding traditional risk assessment paradigms, which have predominantly concentrated on technical and financial aspects, by incorporating social, economic, and political dimensions. This multidimensional approach contributes to the enhancement of theoretical foundations in risk management, facilitating a more nuanced appreciation for the complexities inherent in EV infrastructure projects. Additionally, the study presents new ideas, like using Social Life Cycle Assessment (S-LCA), to look at the social effects of EV infrastructure, filling a major gap in current research that usually ignores social and environmental factors. This expansion helps broaden the theoretical scope of risk and sustainability studies. Additionally, by employing a combination of methodologies—including Fuzzy Logic, Multi-Criteria Decision Making (MCDM), and Conditional Value-at-Risk (CVaR)—the research highlights the value of interdisciplinary approaches in risk analysis. It indicates that risk management theories can be greatly improved by using ideas from engineering, economics, social sciences, and policy studies to create better, more relevant, and stronger solutions.

This study elucidates several practical implications for diverse stakeholders engaged in the planning, development, and regulation of electric vehicle (EV) infrastructure. For policymakers and regulators, the findings furnish valuable insights for crafting more comprehensive and sustainable policies that integrate technical, economic, and social risk considerations. Such policies can facilitate the establishment of a safer, more efficient, and socially advantageous public transportation system. From an engineering and operations perspective, the study helps infrastructure managers improve the safety and reliability of EV charging networks by using advanced risk assessment tools like probabilistic simulation, Conditional Value at Risk (CVaR), and Failure Mode and Effects Analysis (FMEA). These methodologies can assist in mitigating technical failures and ensuring consistent system performance. Additionally, the findings are beneficial for energy and infrastructure practitioners aiming to optimize resource allocation within smart grids and EV charging systems. By incorporating techniques like Monte Carlo simulation and CVaR, practitioners can develop more effective energy management strategies that enhance grid stability and support the integration of renewable energy sources. Furthermore, the integration of Social Life Cycle Assessment (S-LCA) in this research illustrates the value of evaluating social and environmental impacts across the lifecycle of EV technologies, particularly in battery production and recycling. This approach not only promotes environmental sustainability but also bolsters public trust in electric mobility solutions. Overall, this study helps improve risk management ideas by looking at them from a broad and combined perspective, and it is practically important because it leads to better policies, infrastructure, and management practices that create a stronger, more sustainable, and socially responsible electric vehicle system.

6. Conclusion

Summary of Key Findings. This study has found several ways to assess risks when developing electric vehicle (EV) infrastructure, such as probabilistic simulation, Conditional Value-at-Risk (CVaR), Fuzzy Logic, and Multi-Criteria Decision Making (MCDM). Each methodology presents distinct advantages and limitations; for instance, Monte Carlo simulation is proficient in managing uncertainties associated with grid load and charging demand, whereas CVaR excels in addressing extreme risks. Although these methodologies offer valuable insights, the majority of studies predominantly concentrate on technical and financial aspects, with insufficient attention given to the social and environmental dimensions that are crucial for the sustainability of EV infrastructure. Furthermore, the research highlights significant gaps in the application of risk assessment in developing countries, rural areas, and tropical regions, which encounter unique challenges related to energy infrastructure and policy. These findings indicate a need for further research to develop more comprehensive and adaptive risk assessment models that integrate social factors, emerging technologies, and diverse energy policies while addressing environmental challenges influenced by climate change.

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