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Sustainable EV Battery Recycling Infrastructure: A Review of Site Selection Frameworks and Decision Models

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Abstract: The rapid rise of electric vehicles (EVs) highlights the urgent need for sustainable infrastructure, especially for end-of-life battery recycling and charging station siting. This systematic literature review (SLR) analyzes 68 peer-reviewed studies published between 2015 and 2024, focusing on decision-making frameworks and sustainability criteria for EV battery recycling (EVBR) site selection. Following the PRISMA protocol, the review applied a structured process of identification, screening, and inclusion. Nearly 48.5% of the studies specifically address EVBR siting. Thematic analysis reveals widespread use of tools such as multi-criteria decision-making (MCDM), Geographic Information System (GIS), and hybrid AHP-TOPSIS models. However, comprehensive sustainability assessments and geo-spatial integration remain inconsistent, and few studies propose adaptive frameworks that align with changing urban policies and energy trends. This review maps the current methodological landscape, uncovers gaps such as limited circular economy practices and stakeholder involvement, and suggests future research directions to build resilient, eco-efficient EV battery recycling infrastructure.

Keywords*: Electric Vehicle; Battery Recycling; Charging Station Siting; Decision-Making Frameworks; Sustainability; MCDM; Systematic Literature Review.*

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I. INTRODUCTION

The growing conflict between resource use and human development has drawn more and more attention to electric energy as a clean energy source for environmental preservation and the growth of green manufacturing. The EV battery sales have been steadily rising under various national regulations in recent years due to the strong support that EV batteries have received from nations worldwide [1]. People are becoming more accepting of EVs as a result of significant government subsidies and growing environmental consciousness. As of 2019, the number of electric vehicles worldwide has increased to 7.1 million, according to the International Energy Agency [2]. The fact that 16.5 million electric vehicles were sold worldwide in 2021, accounting for about 10% of the automotive market, makes the phenomenon evident [3]. Furthermore, this change is consistent with more general sustainability objectives, as seen by the sharp increase in EV sales worldwide, which are expected to reach 15 million units by 2025 and a staggering 25 million by 2030 [4]. Batteries are essential components of EVs, and their number is rapidly increasing in tandem with the EV market's continued major growth [5] [6]. Table 1 illustrates the disparities in performance between different power batteries (such as Pb-Acid, Ni-MH, Ni-Cd, Li-ion, graphene-based, and all-solid-state batteries) [7] [8] [9] [10]. Li-ion batteries have taken the lead among EV batteries because of their superior performance in real-world applications, including energy efficiency and cycle times [12]. Even though next-generation batteries have demonstrated impressive qualities in their own right, their high cost, toxicity, and limited material supply prevent them from being widely utilized in automobiles or other transportation equipment.

The lithium-ion battery (LIB), which is related to environmental sustainability, high power density, and energy efficiency, is essential for developing this growing industry [13]. However, the service life of EV batteries is roughly 6–8 years [14], and the LIB for EV will be recycled when the residual capacity is reduced to 70–80% of the original capacity [15]. Given the increasing trend of EV use, retired EV batteries will eventually become widely available, reaching 117 GWh in 2025 and 280 GWh in 2030, respectively [16]. Even though retired batteries don't last very long in real-world applications, they still have enough energy left over and can be reused in other contexts (like energy storage, low-power EVs, etc.) [17] and can recycle a lot of precious metal elements [18]. Battery recycling has major positive effects on the economy, the environment, and society, and is essential to the

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shift to a worldwide circular economy [19]. This procedure helps to lessen adverse environmental effects in addition to facilitating the reuse of limited resources. More significantly, battery recycling contributes significantly to job creation [20]. The future of battery recycling is bright. On the one hand, economies of scale for battery recycling will materialize as the quantity of retired batteries rises sharply. However, many nations in the battery recycling sector actively advocate battery recycling as the final step in the process of creating new energy and protecting the environment [21].

Table 1 Comparison of the Performances of Several Power Batteries [11]

Characteristics	NiCd	Lead Acid	Graphene-based Battery	Li-Ion	All-Solid-State Battery	NiMH
Normal Voltage (V)	1.2	2.0	/	3.6	/	1.2
Power (W/kg)	200	130	>600	330	/	250
Energy (Wh/kg)	45-80	30-50	600	100	200-500	60-120
Energy Efficiency (%)	80	65	/	95	/	85
Cycle life (times)	500-1000	200-300	>1000	1000	2000-3000	300-500

Nevertheless, setting up sustainable battery recycling infrastructure is a sophisticated challenge, and it goes beyond technological concerns. A critical component of this infrastructure development is locating recycling plants in the best possible site. The location affects the efficiency of logistics, environmental impact, economic feasibility, and public acceptance. Notwithstanding its importance, EV battery recycling site selection has been the subject of limited systematic investigation in the literature to date relative to process technological advancements in recycling [22]. Conventional siting techniques fall short of reconciling the multidimensional trade-offs between environmental, social, technical, and economic factors. Therefore, sophisticated decision models and exhaustive frameworks must be used to update site selection within this promising industry.

➢ *Objectives:*

- Synthesize current frameworks and decision-support models related to sustainable EV battery recycling, with an emphasis on their relevance to facility siting and infrastructure planning.
- Analyze the technical, environmental, economic, and social factors used in EV battery recycling studies that can inform the location and design of recycling infrastructure.
- Compare and evaluate decision-making methods used for facility planning in terms of effectiveness, assumptions, and adaptability.
- To identify key research gaps and suggest directions for future studies focused on building resilient, dynamic, and technology-integrated EV battery recycling systems.

➢ *Research Questions:*

This comprehensive investigation is guided by the following research questions (RQs):

- RQ1: What frameworks and decision-support models have been used to guide the development of sustainable EV battery recycling systems, and how do they inform facility siting and infrastructure planning?
- RQ2: What key technical, environmental, economic, and social criteria are considered in EV battery recycling research, and how can these inform facility site selection decisions?
- RQ3: How do different decision-making approaches compare in terms of their applicability, strengths, and limitations for EV battery recycling infrastructure planning, including site selection?
- RQ4: What are the critical gaps and emerging opportunities for future research in integrating advanced technologies into EV battery recycling and site selection models?

This SLR is a strong academic and practical contribution by bringing a broad synthesis of site selection frameworks and decision models to the setting of sustainable EV battery recycling infrastructure. As EV uptake gets faster across the world, the urgent need to manage end-of-life (EoL) batteries calls for strong, sustainable, and strategically located recycling plants. Although individual research has touched on different aspects of facility location planning, the literature is still fragmented, with minimal integration of sustainability factors, resilience, and cutting-edge decision-support technologies. This review fills these gaps by providing an integrative view that synthesizes knowledge from disciplines like operations research, environmental science, engineering, and decision analytics.

The remainder of this SLR paper is structured as follows: Section 3 outlines the methodology of review, adhering to the PRISMA protocol, including search strategies, inclusion/exclusion criteria, and data extraction methods. Section 3 provides a descriptive analysis of selected literature, covering publication trends, disciplinary distributions, and decision-model typologies. Section 4 carries a thematic synthesis organized around four RQs, specifying the evolution of site selection frameworks, criteria considered, comparative evaluations, and research gaps. Section 5 discusses the implications of findings, outlines limitations in the literature, and proposes a forward-looking research schedule. Section 6 provides the future scope of this research. Section 7 concludes the paper by summarizing key insights and reinforcing the urgent need for interdisciplinary, technologically-enabled methods to sustainable EV battery recycling infrastructure.

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II. LITERATURE REVIEW

➢ *Frameworks and Decision-Support Models for EV Battery Recycling*

The literature on frameworks and decision-support models for EV battery recycling infrastructure reveals a strong reliance on MCDM techniques, which systematically evaluate potential sites based on technical, economic, environmental, and social factors. For instance, studies such as Sherif et al. [25] and Afroozi et al. [92] combined fuzzy Analytic Hierarchy Process (AHP), fuzzy COPRAS, and Interpretive Structural Modeling (ISM) to prioritize sustainable locations for battery recycling plants in India, addressing uncertainties in expert judgments. Similarly, Puviarasu et al. [28] and Feng et al. [44] employed the Best-Worst Method (BWM) to determine criteria weights and Cumulative Prospect Theory (CPT) to rank alternatives, emphasizing resilience and risk-aware decision-making. Other hybrid approaches, like Puviarasu et al. [28], integrated fuzzy DEMATEL with BWM and TOPSIS to model interdependencies among criteria such as policy constraints, technological feasibility, and logistical efficiency.

The GIS has also been widely adopted to enhance spatial decision-making. Ghosh et al. [42] and Erbaş et al. [43] coupled fuzzy AHP-TOPSIS with GIS to identify optimal locations for EV charging stations by analyzing population density, energy demand, and infrastructure accessibility. Meanwhile, Nguyen-Tien et al. [49] and Hendrickson et al. [52] used GIS-based LCA to optimize the placement of dismantling and recycling facilities, minimizing transportation-related emissions. These models highlight the importance of geospatial data in ensuring both economic and environmental efficiency. To address uncertainty and dynamic market conditions, researchers have incorporated advanced probabilistic and fuzzy methods. For example, Wu et al. [24] applied Triangular Intuitionistic Fuzzy Numbers (TIFNs) to handle subjective judgments in siting EV charging stations within residential communities. Triangular Intuitionistic Fuzzy Numbers (TIFNs) is a more complex fuzzy logic technique that is applied in dealing with uncertainty and vagueness in expert judgments in complex decision-making, particularly in situations where no precise information is available. They assist in expressing the degrees of membership and non-membership at the same time. Bayesian Networks (BNs) are probabilistic models that describe dependencies between various influencing factors. BNs assist in quantifying the risks and making predictions in uncertainty during site selection. Hosseini and Sarder [29] introduced a Bayesian Network (BN) model to assess qualitative and quantitative factors, such as policy risks and stakeholder preferences, while Mishra et al. [35] utilized Single-Valued Neutrosophic Sets (SVNSs) to reduce ambiguity in selecting lithium-ion battery (LiB) manufacturing plants. These approaches demonstrate the growing need for models that can adapt to incomplete or imprecise data.

Circular economy principles have further influenced decision frameworks, particularly in closed-loop supply chain (CLSC) optimization. Studies such as Pamucar et al. [50] and Debbarma et al. [76] developed models that balance cost, carbon emissions, and material recovery rates, while Wei et al. [78] employed process-based LCA to evaluate trade-offs between different recycling technologies (e.g., pyrometallurgy vs. hydrometallurgy), where Pyrometallurgy involves the extraction of metals such as lithium and cobalt in batteries using high temperatures, and is energy-intensive. Hydrometallurgy involves lower temperatures, chemicals, more environmentally friendly, resulting in a greater metal recovery rate. The batteries based on graphene are faster charging, have more energy storage capacity, and last longer than regular batteries, but remain in the research phase.

Emerging computational approaches, including machine learning (ML) and game theory, have also gained traction. For instance, Haynes et al. [55] applied unsupervised clustering to decentralize preprocessing facilities in California, reducing logistical costs, and Hu et al. [75] and Xiao et al. [87] used Stackelberg game theory to analyze how subsidies and carbon pricing influence recycling network profitability. Despite these advancements, several research gaps remain. Most models assume static criteria weights and fail to integrate real-time data, limiting their adaptability to market fluctuations. Additionally, few frameworks explicitly account for evolving policy landscapes, such as carbon pricing or subsidy phase-outs. Scalability is another challenge, as GIS-based models often rely on region-specific data, hindering broader applicability. The development of digital twin simulations using IoT data could further improve resilience in infrastructure planning, while transnational frameworks are needed to address global material flows, as highlighted in [57] and [72]. Collectively, these insights underscore the need for more adaptive, technology-integrated decision-support systems to advance sustainable EV battery recycling infrastructure.

➢ *Criteria for EV Battery Recycling Site Selection*

Sustainable EV battery recycling infrastructure requires a comprehensive evaluation of technical, environmental, economic, and social factors to optimize facility siting decisions. Technical criteria play a pivotal role, with considerations such as battery chemistry (e.g., NCM, LFP) and compatibility with recycling methods (e.g., hydrometallurgy, pyrometallurgy) influencing process efficiency [49, 65, 80]. Logistics and infrastructure readiness, including proximity to transportation networks and industrial hubs, significantly reduce operational costs [44, 55, 76]. Additionally, advancements in automation (e.g., human-robot collaboration [88]) and pre-treatment technologies (e.g., pyrolysis [69]) enhance scalability and flexibility, ensuring facilities can adapt to future battery volumes and evolving chemistries [57, 72]. Environmental sustainability is another critical dimension, with carbon footprint assessments (e.g., LCA of hydrometallurgical vs. pyrometallurgical emissions [52, 78]) guiding eco-friendly site selection. Proper hazardous waste management (e.g., electrolyte and heavy metal disposal [45, 65]) and high resource recovery rates (e.g., cobalt, lithium [53, 81]) are essential for minimizing ecological harm. Land use planning must also avoid ecologically sensitive areas while ensuring compliance with environmental regulations [42, 43]. Economic viability is a decisive factor, with capital and operational costs such as labor, energy, and raw material

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expenses varying regionally [57, 76]. Transportation costs can be minimized by locating facilities near EV manufacturers, collection centers, and secondary material markets [54, 85]. Government incentives, including subsidies and carbon pricing mechanisms (e.g., cap-and-trade [87]), further enhance profitability [56, 62], while stable demand for recycled materials (e.g., echelon-use in energy storage [82]) ensures long-term feasibility.

Social and policy considerations are equally vital, as community acceptance of recycling facilities based on perceptions of safety and noise pollution can determine project success [27, 44]. Access to a skilled workforce supports advanced recycling operations [35, 88], while alignment with regulatory frameworks (e.g., EU Battery Directive) ensures compliance [59, 72]. Emerging digital solutions (e.g., IoT [59]) improve traceability and transparency, fostering stakeholder trust. However, trade-offs often arise between competing priorities. High-efficiency recycling methods (e.g., direct recycling [57]) may incur greater costs, while centralized plants, though cost-effective, increase transportation emissions [54, 55]. Policy-driven incentives, while accelerating infrastructure development, risk creating long-term dependencies [59, 91]. Recent studies also emphasize resilience (e.g., disaster risk mitigation [44]) and circular economy integration (e.g., remanufacturing [54, 75], second-life applications [81]) as emerging priorities. To address these complexities, hybrid decision-making frameworks (e.g., MCDM-GIS integration [32, 52]) are increasingly employed. For instance, fuzzy AHP-TOPSIS models prioritize environmental and social factors in densely populated regions [39, 40, 42, 43, 46], while cost-driven models favor areas with policy incentives and low labor costs [62]. Despite these advancements, gaps remain in incorporating dynamic criteria (e.g., evolving battery technologies, policy shifts) and quantitatively assessing community engagement [44]. This synthesis underscores the need for adaptive, multi-criteria approaches to optimize EV battery recycling infrastructure planning.

➢ *Decision-Making Approaches*

The literature on EV battery recycling infrastructure planning employs a diverse range of decision-making approaches, each with distinct strengths, limitations, and applicability for facility siting. These methods can be broadly categorized into multi-criteria decision-making (MCDM) models, hybrid frameworks, game theory and optimization techniques, ML and AI-driven approaches, and uncertainty-management strategies. MCDM models are the most widely used due to their structured evaluation of multiple sustainability criteria. Fuzzy AHP [25] [32] [37] [42] [43] and ANP [36] are frequently applied for weighting criteria under uncertainty but are criticized for subjectivity in expert judgments. TOPSIS [28], VIKOR [37], and ELECTRE [32] rank alternatives based on their proximity to ideal solutions, making them effective for trade-off analysis, though their outcomes are sensitive to normalization techniques. PROMETHEE [36] [37] [38] excels in handling non-compensatory criteria but requires precise threshold definitions, while MULTIMOORA [30] [33] [63] [69] offers robustness for heterogeneous data at the cost of computational intensity. Hybrid frameworks integrate multiple methodologies to address complex interdependencies. Fuzzy DEMATEL-BWM-TOPSIS [28] [46] effectively captures causal relationships among criteria but becomes cumbersome for large-scale problems. Cumulative prospect theory (CPT) combined with BWM [26] [44] incorporates behavioral economics, accounting for decision-makers' risk aversion, but relies heavily on expert inputs. GIS-MCDM hybrids [32] [37] [42] enhance spatial suitability assessments but demand high-resolution geospatial data, limiting their accessibility.

Game theory and optimization models provide strategic insights into stakeholder interactions. Stackelberg game models [74] [86] [91] analyze policy-manufacturer-recycler dynamics but often assume rational behavior, overlooking real-world complexities. Linear and integer programming [34] [51] optimize cost and emissions but struggle with dynamic uncertainties such as fluctuating material prices and evolving regulations. ML and AI are emerging as powerful tools for dynamic decision-making. Unsupervised clustering algorithms [55] help identify optimal facility locations but lack transparency in decision rules. Multi-agent reinforcement learning [87] improves disassembly efficiency in recycling operations but requires extensive training data, posing challenges for early-stage implementation. Uncertainty-management techniques enhance decision robustness in ambiguous environments. Neuromorphic and Pythagorean fuzzy sets [63] [66] handle vagueness effectively but increase computational complexity. Bayesian Networks (BNs) [29] quantify probabilistic risks but need extensive calibration data, while entropy-based methods [27] [45] [47] [53] [69] objectively derive criteria weights but may overlook qualitative factors. A critical trade-off exists between methodological rigor and practical applicability. While MCDM and hybrid models dominate due to their structured workflows, they often fail to account for real-world dynamism, such as evolving battery chemistries or policy shifts [28] [46]. Uncertainty-handling techniques (e.g., fuzzy sets, BNs) improve decision robustness but at the cost of increased complexity. Game theory [86] [90] and system dynamics [56] [59] [89] provide macro-level policy insights but lack granularity in site-specific planning. The Overall Summary of the Published paper is illustrated in table 2.

Table 2 Overall Summary of the Published Paper

Group	Methods	Advantages	Disadvantages	Applications	papers
MCDM	Fuzzy AHP, ANP, TOPSIS, VIKOR, ELECTRE, PROMETHEE, MULTIMOORA	Well-formulated multi-criteria that are effective in trade-offs	Subjective expert opinion, normalization sensitivity, Computational complexity	Weighting of criteria, ranking of alternative sites and evaluation of sustainability	[25] [27] [28] [30] [32] [33] [36] [37] [38] [42] [43] [63] [69]

Hybrid models	Fuzzy DEMATEL-BWM-TOPSIS, CPT-BWM, GIS-MCDM	Able to record complex interrelated dependencies and spatial assessment	Data intensity that renders large-scale issues less convenient	Modeling of causal relationship, integration of trade-offs, and spatial analysis	[26] [28] [32] [37] [42] [44] [46]
Game Theory and Optimization	Stackelberg Game, Linear Programming, Integer Programming	Measurement of stakeholder dynamics, recorded costs, and optimization of emissions	Finds itself unable to manage dynamic uncertainties, and rational behavior is usual	Modeling of stakeholder interaction, minimization of costs, and control of emissions	[34] [51] [74] [86] [91]
Approaches with ML and AI	Clustering Algorithms, Multi-Agent Reinforcement Learning	The effectiveness of operations is enhanced by dynamic decision-making	The transparency problem, data-intensive, and limitations at the nascent stage	Identification of optimal facility locations, and automation of its processes	[55] [87]
Uncertainty-management	Neuromorphic Fuzzy Sets, Pythagorean Fuzzy, Bayesian Networks, Entropy Methods	Ambiguity control, enhanced resilience, and objective weighting are used	It requires costly calculation and intensive calibration	Uncertainty management, risk dealing, and derivation of weight of criteria	[27] [29] [45] [47] [53] [63] [66] [69]

III. REVIEW METHODOLOGY

This SLR broadly synthesizes the literature on current decision models and frameworks that apply to sustainable EV battery recycling facility site selection. A systematic approach provides a comprehensive, reversible, and objective synthesis of the literature because the topic is broad and includes engineering, operations research, and environmental science. The review protocol was developed according to the PRISMA guidelines [23], which deliver a standardized approach to conducting and reporting systematic reviews. PRISMA statement makes clarity of rationale, methodology, and findings of systematic reviews a highest priority, which eventually makes them reliable and useful in updating policy and practice. By following PRISMA, this review preserves methodological consistency through a well-defined research protocol with objectives, inclusion/exclusion criteria, and data extraction procedures, thorough search strategy in multiple databases to identify relevant studies, transparent selection process recorded through PRISMA flow diagram, and systematic data extraction and thematic synthesis according to predefined research questions. This systematic method allows for the identification of research gaps and the development of evidence-based recommendations for future research and practical use in the area of sustainable EV battery recycling infrastructure. Figure 1 presents the PRISMA flow diagram.

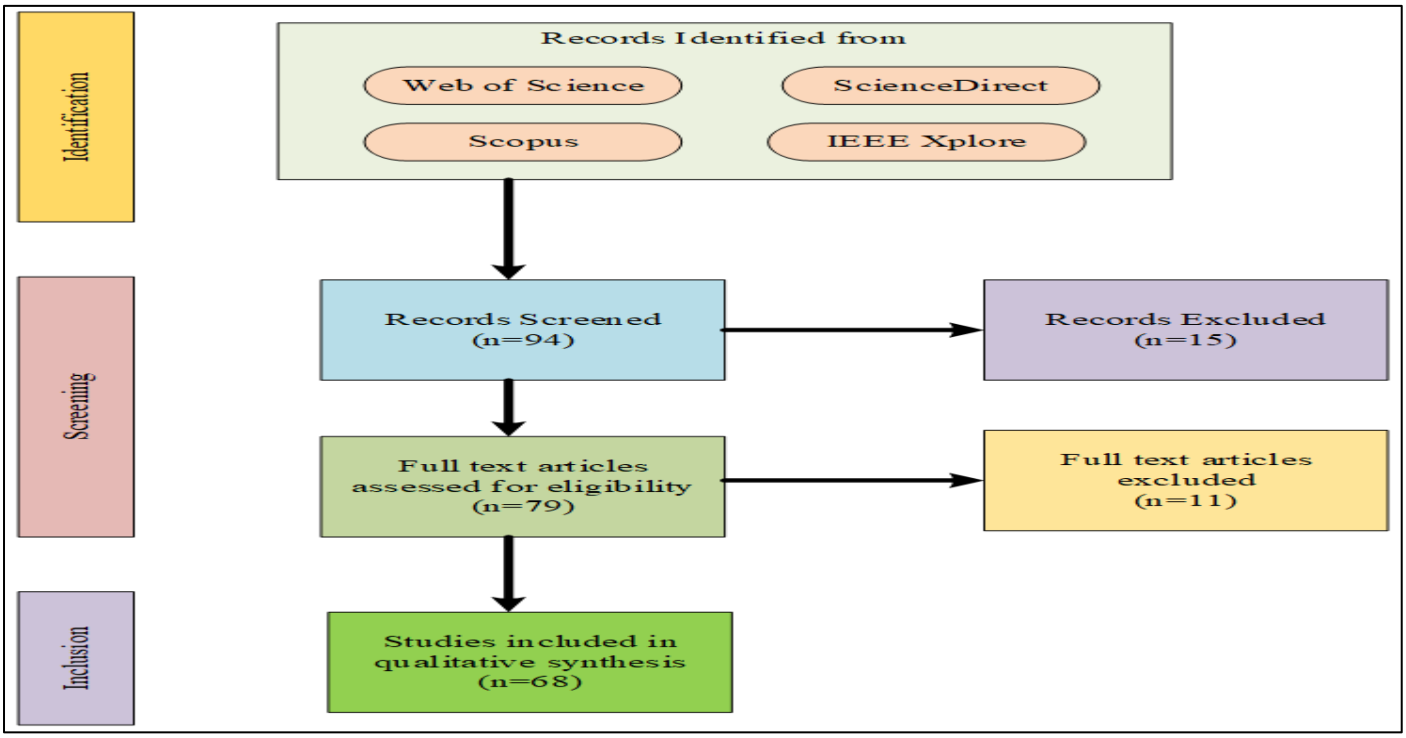

Fig 1 PRISMA Flow Diagram

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➤ *Search Strategy*

In alignment with PRISMA guidelines, a comprehensive search strategy was developed to identify relevant literature on site selection frameworks and decision models for sustainable EV battery recycling infrastructure. The search was conducted across various databases to ensure a broad collection of studies. This study conducted a literature search across Web of Science (WoS), ScienceDirect, Scopus, and IEEE Xplore databases. These four databases were selected for their extensive coverage of engineering, environmental science, and decision-making literature pertinent to the research topic.

The search strategy was formulated using a combination of controlled vocabulary and free-text terms to capture the breadth of relevant literature. The primary keywords, such as sustainable EV battery, site selection, EV battery recycling, facility location, and decision models, are used. Boolean operators were employed to structure the search strings effectively. The study used search query of ("lithium-ion battery recycling" OR "electric vehicle battery recycling" OR "EV battery recycling" OR) AND ("sustainability" OR "social impact" OR "environmental impact" OR) AND ("site selection" OR "location planning" OR "facility location") AND ("decision model" OR "multi-criteria decision making" OR "MCDM" OR "optimization").

To ensure the quality and applicability of studies incorporated, various constraints were applied during the process of searching. As an initial constraint, only those English-language articles that were available for access and readability were chosen. The search was restricted to publications in peer-reviewed journals and conference proceedings and was excluded from grey literature, reports, and dissertations, which are not peer-reviewed. This is to guarantee high-quality, tested research included. Concerning the date of publication, only those studies published between the years 2015 and 2025 were included to allow the review to capture the latest research trends and approaches in the fast-changing field of EV battery recycling. Additionally, the search was targeted specifically at publications in the subject domains of engineering, environmental science, and operations research, which form the core of site selection and decision models for recycling facilities. Research that did not target EV battery recycling directly, or research without a decision-making framework for facility location, was excluded, as were publications concerning general waste management and logistics with no direct relevance to facility location planning. These exclusions served to limit the review's scope while permitting only the highest-relevance and methodologically sound studies to be considered.

➤ *Inclusion and Exclusion Criteria*

The SLR must have well-defined and clear inclusion and exclusion criteria to be transparent, reproducible, and methodologically effective. The full text of 68 collected articles was further examined based on the following eligibility criteria, as shown in Table 3.

Table 3 Summary of Inclusion and Exclusion Criteria

Criteria Category	Inclusion	Exclusion
Topical Focus	EV battery recycling site selection; EOL battery management	General waste or logistics studies without a specific focus on EV batteries
Sustainability Focus	Addresses at least one sustainability dimension (environmental, economic, social)	Purely technical/logistical models without sustainability considerations
Decision Component	Includes decision models/frameworks (e.g., MCDM, GIS, optimization, AI)	Lacks structured decision-making methodology
Language	English	Non-English publications
Publication Date	Published between January 2015 and March 2024	Published before 2015
Publication Type	Peer-reviewed journal articles	Conference papers, reports, theses, and grey literature
Methodological Rigor	Conceptual frameworks or empirical applications relevant to siting decisions	Opinion pieces, reviews without analytical depth, or anecdotal discussions

➤ *Screening and Selection*

The screening process for this systematic literature review was conducted in two distinct phases to ensure methodological rigor and the inclusion of only the most relevant and high-quality studies. In the initial identification stage, a total of 109 records were retrieved from five major academic databases such as Scopus, WoS, IEEE Xplore, ScienceDirect, and SpringerLink using a structured set of keywords and Boolean combinations related to EV battery recycling, EV charging station site selection, sustainability, and decision-making frameworks. After removing 15 duplicate records, 94 articles remained for the first level of screening. The first phase involved title and abstract screening to eliminate studies that were irrelevant to the research objectives. This process resulted in the exclusion of 15 studies that either lacked a decision-making component, did not pertain to EV battery recycling or EVCS siting, or failed to address sustainability dimensions. In the second phase, the remaining 79 full-text articles were thoroughly reviewed against the predefined inclusion and exclusion criteria. Each article was assessed independently by two reviewers, and any disagreements were resolved through discussion and consensus. Following this detailed full-text evaluation, 11 articles were excluded. The most common reasons for exclusion included the absence of an explicit decision-making framework, insufficient focus on sustainability aspects, or a lack of methodological detail that precluded replication or comparative analysis. Ultimately, 68 studies met all inclusion criteria and were considered suitable for qualitative synthesis. These selected studies form the empirical foundation for the

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thematic analysis and findings presented in the subsequent sections of this review.

IV. RESULT AND DISCUSSION

The SLR was performed according to PRISMA guidelines in Web of Science, Scopus, ScienceDirect, and IEEE Xplore to find the high-quality studies of site selection frameworks and decision models to recycle EV batteries sustainably. There were a combination of free-text terms and controlled vocabulary such as EV battery recycling, sustainability, site selection, facility location, decision models along with use of Boolean operators to provide maximum relevance in search. The literature search was restricted to peer-reviewed journal articles published between 2015 and 2025, within the field of engineering, environmental science and operations research. Non-grey and general waste management studies were omitted and so were non-specific researches without the decision making or site selection component, so that only sound methodological and highly relevant researches would be included.

A. Key Components of EV Lithium-Ion Battery Recycling Based on the Circular Economy

Each EV LIB research element's alignment with the circular economy's components is explained in the mapping that follows [92]. The circular economy model's application to the recycling of EV LIBs is covered in Figure 2.

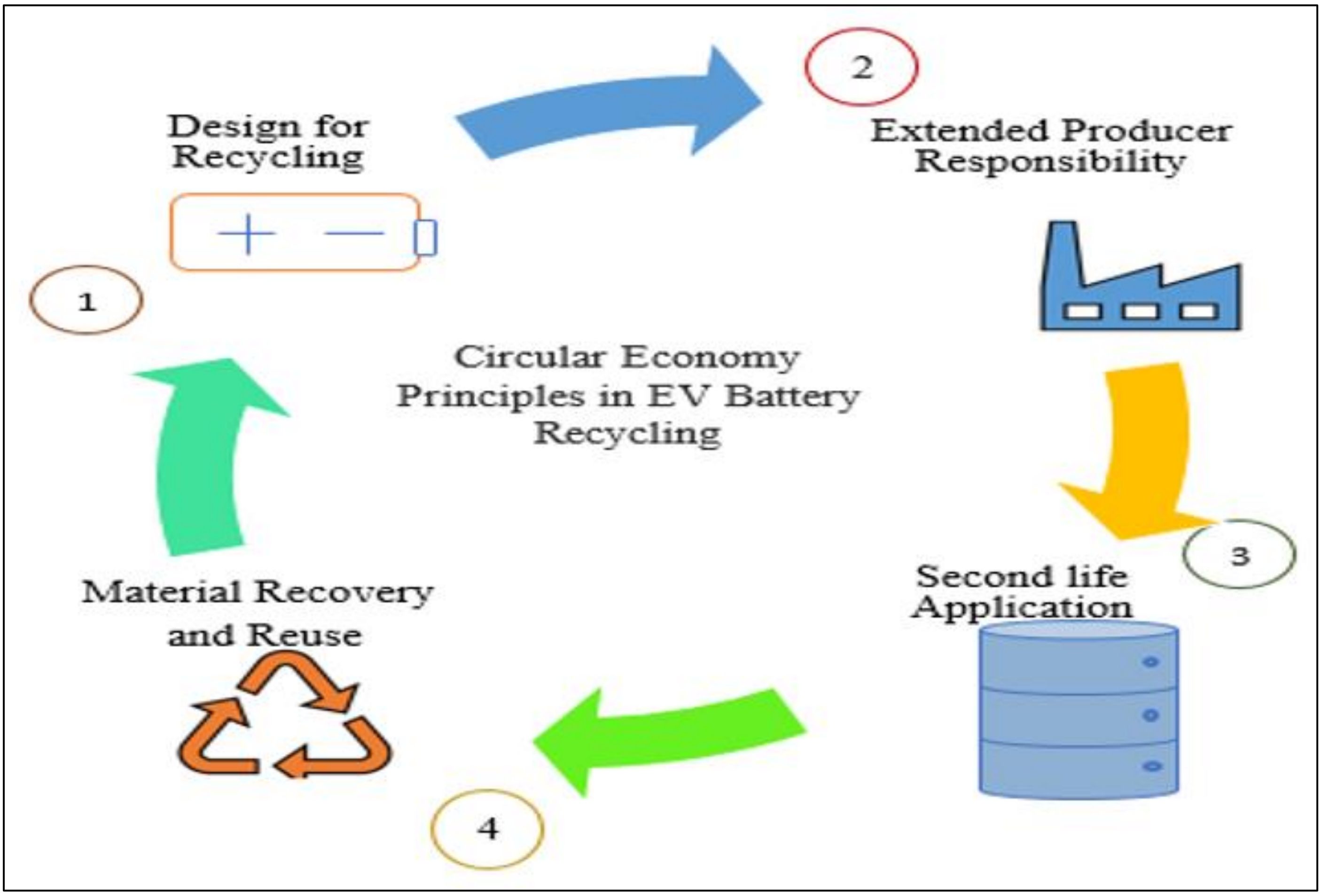

Fig 2 Circular Economy Principles in EV Battery Recycling [92], [95]

➢ *Design for Recycling:*

The battery design stage marks the beginning of the use of circular economy concepts. To efficiently recover important materials like lithium, cobalt, and nickel, batteries are designed for lifetime, ease of disassembly, and recyclability. Throughout their life, batteries' environmental effect is reduced and waste is reduced because of this design approach [93], [95].

➢ *Extended Producer Responsibility (EPR):*

To use the circular economy in the EV battery industry, EPR programs are essential. EPR regulations encourage producers to take accountability for the whole lifecycle of their goods, from manufacturing to disposal, which encourages the development of more recyclable and sustainable batteries. This fosters a market environment in which recycling and sustainable design are crucial elements of corporate plans [94], [95].

➢ *Second-Life Applications:*

Making energy storage systems out of EV batteries shows how to make the most use of both materials and products. Batteries that are no longer appropriate for automobiles can be reused to increase their lifespan, postpone disposal, and reduce the demand for new raw materials [92], [95].

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➢ *Material Recovery and Reuse:*

State-of-the-art recycling techniques effectively separate vital components from spent electric vehicle batteries. This diminishes the impact of mining operations on the environment and society and reduces reliance on the extraction of fresh resources. The cycle is completed by using recycled materials in the production of new batteries, which reflects the circular economy's material circulation concept [92], [95].

➢ *Technological and Economic Challenges:*

It is acknowledged that ongoing advancements are crucial to removing barriers to circular economy principles, such as limitations in current recycling technology and economic viability [92].

B. *Comparative Analysis*

In this section, Table 4 shows the distribution of the reference papers by year of publication. Most of the research works have been published over the past few years, which is an indication of increased global concern over EV battery recycling. particularly, the largest number of papers belongs to 2024, which indicates the fast development of sustainable recycling technologies and decision-support models. This trend shows that the research is being directed more towards the integration of the circular economy and EV battery infrastructure planning.

Table 4 Comparative Analysis Based on Years

Years	Reference Papers
2024	[4], [20], [26], [40], [44], [48], [55], [58], [59], [74], [76], [77], [86], [91], [92].
2023	[6], [10], [11], [27], [28], 35], [45], [46], [60], [87], [90], [94].
2022	[2], [3], [19], [21], [22], [25], [31], [32], [38], [47], [49], [50], [53], [62], [63], [75], [78], [84], [88], [93].
2021	[5], [15], [16], [18], [23], [42], [57], [79], [81].
2020	[13], [30], [37], [54], [61], [66], [67], [68], [70], [73], [82], [83], [85].

The figure 3 shows how the various research procedures used to recycle EV battery infrastructure are distributed. The literature is dominated by MCDM techniques as they are the most popular methods of multi-criteria evaluation. Probabilistic models and GIS-based techniques are also very popular, which allows uncertainty and spatial analysis. The models of a circular economy are considerably limited, though increasing in use, which demonstrates a high potential of research in the future.

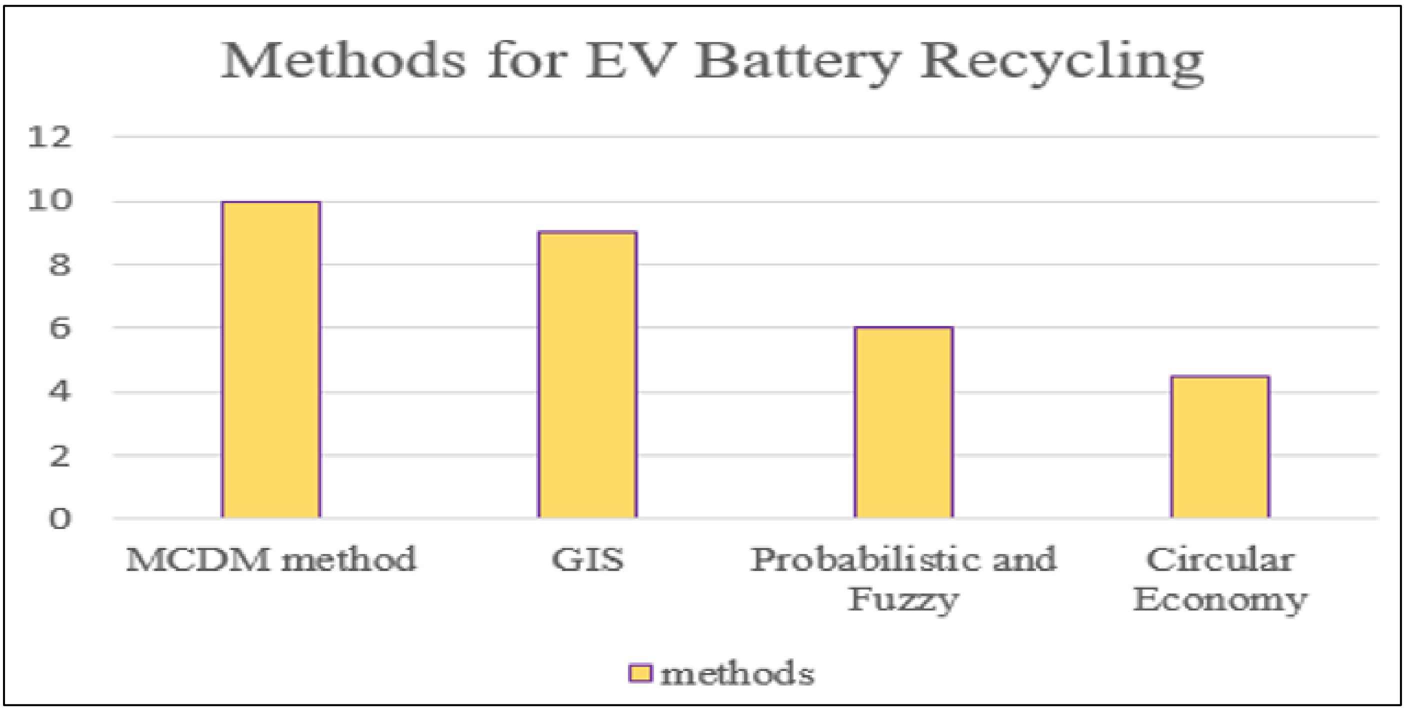

Fig 3 Methods used for EV Battery Recycling

Figure 4 shows the comparative analysis of references by the journal sources. It points out that journals such as Applied Energy, Journal of Cleaner Production, and Sustainability have the most contributions in terms of studies because they have been very keen on research on EV battery recycling and circular economy. Such distribution highlights the focus of the relevant literature on the top sustainability and energy-oriented journals.

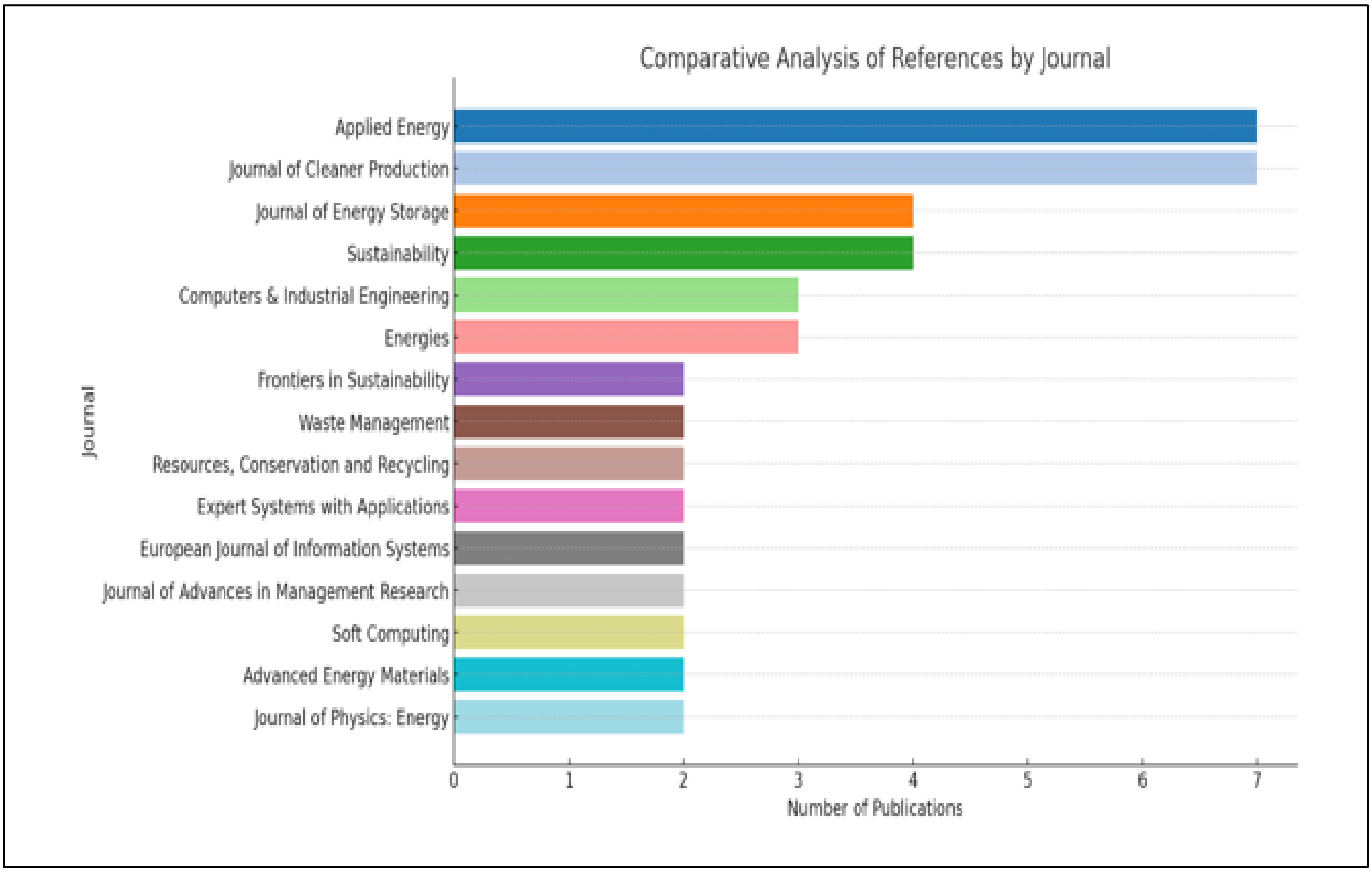

Fig 4 Comparative Analysis Based on Journals

In order to confirm the most popular techniques and primary applications, among other contributions, a more thorough analysis was conducted based on the bibliometric analysis of the papers. Table 5 summarizes the issues discussed in the publications.

Table 5 Applications

Applications	Occurrences	References
Battery Recycling Site Selection	12	[6], [26], [34], [47], [48], [49], [54], [55], [57], [65], [75], [86]
Second-Life Battery Applications	7	[15], [34], [81], [85], [91], [94], [95]
Circular Economy Integration	9	[19], [20], [22], [34], [49], [75], [81], [94], [95]
Life Cycle Assessment (LCA) of Batteries & EVs	11	[10], [11], [13], [14], [26], [49], [55], [73], [80], [86], [91]
Supply Chain and Logistics Optimization for Recycling	6	[54], [57], [62], [65], [75], [91]
Environmental Impact Variation by Region (Power Mix)	8	[4], [16], [18], [83], [94], [95], [96]
Policy-Driven Recycling Models	5	[6], [59], [60], [61], [86]
Geographic Suitability for Recycling Infrastructure	6	[26], [49], [55], [75], [86], [91]
Socio-Economic Impact Considerations	4	[22], [27], [45], [88]
Battery Production Emissions and Energy Consumption	7	[6], [34], [47], [48], [54], [57], [65]
Technology-driven Smart Recycling (AI, IoT, etc.)	3	[34], [82], [87]
Resilient Site Planning and Environmental Risks	3	[26], [49], [55]
Global Case Studies on Recycling Infrastructure	5	[4], [16], [18], [83], [91]

Figure 5 presents the sensitivity analysis of recycling EV battery infrastructure. Such major factors that influence it are policy incentives, socio-economic acceptance, and battery life expectancy. The environmental as well as economic outcomes are relatively influenced by power generation mix and technology selection.

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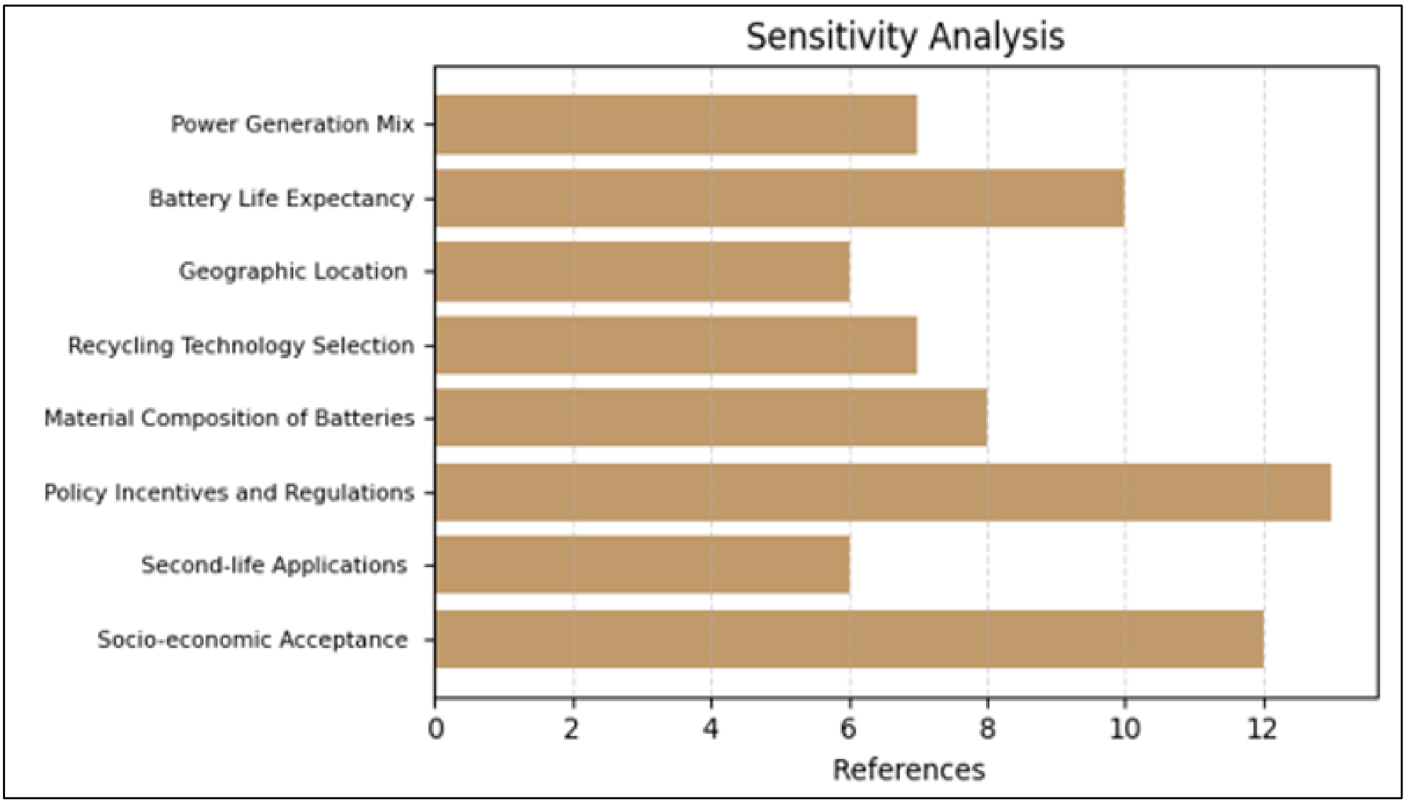

Fig 5 Sensitivity Analysis

The figure 6 shows how the amount of publications on EV battery recycling site selection is expected to grow annually in the period 2015-2024. Constant growth can be noticed with a minimum output in 2015-2017, then a constant growth with a maximum in 2023 with 11 publications. The sharp growth after 2020 shows an appropriate increase in interest in the world caused by the needs of sustainability and a circular economy. The minor decrease in 2024 reveals a continued research momentum but shows that there is an area where it could be explored even more.

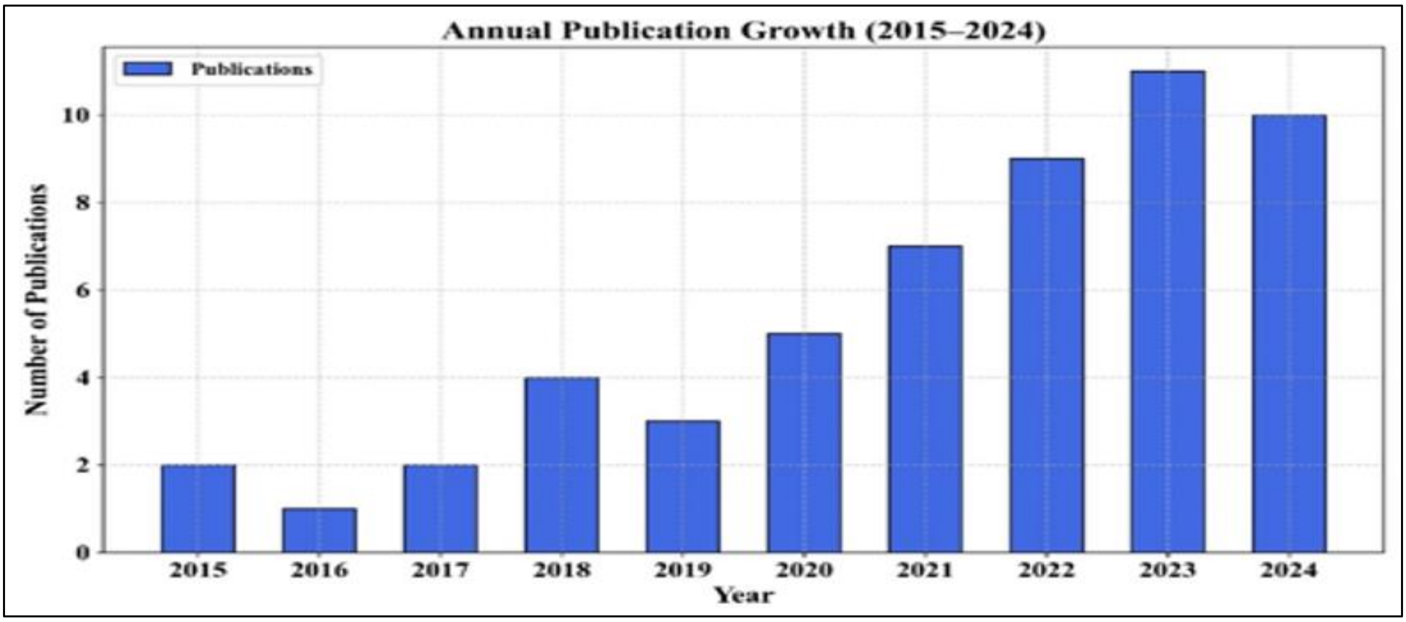

Fig 6 Annual Publication Growth

Figure 7 demonstrates a geographical distribution of the EV battery recycling research works. Asia contributes the largest to the research output with 60 %, which portrays strong focus on the battery supply chains and the recycling infrastructure within the region. There is moderate academic activity with 25 % in Europe and 10 % in North America. The remaining regions represent a small percentage of 5 which means that there are not many different research in this field globally.

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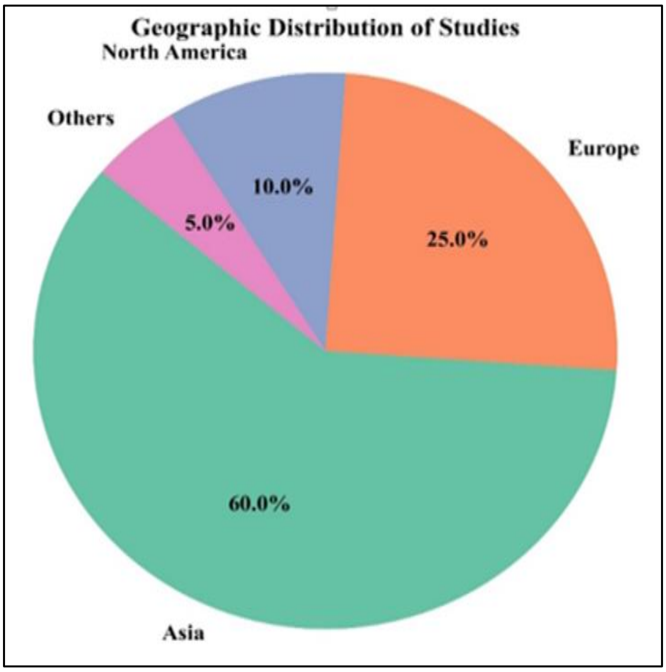

Fig 7 Geographic Distribution of Studies

V. FUTURE SCOPE: GAPS AND EMERGING OPPORTUNITIES

The systematic review reveals several critical gaps in current research on EV battery recycling infrastructure planning, along with emerging opportunities for future studies. One major limitation is the lack of dynamic and adaptive decision models. Most existing frameworks, such as MCDM and GIS-based approaches, rely on static criteria and deterministic inputs, failing to account for real-world complexities like market volatility, evolving battery chemistries, and policy shifts. For instance, while Gu et al. [56] and Mo and Jeon [72] highlight the need for adaptive models, few incorporate real-time supply chain dynamics. Another gap is the limited integration of resilience metrics with sustainability criteria. Although Feng et al. [26] and Feng et al. [44] explored resilience factors like climate adaptability, they often neglect circular economy principles, such as second-life applications [82] and closed-loop supply chains [60] [70] [86] [90]. Additionally, many MCDM approaches depend heavily on theoretical assumptions, with limited empirical validation. Hendrickson et al. [52] and Wang et al. [54] demonstrate discrepancies between modeled outcomes and operational realities, underscoring the need for more data-driven decision-making. Fragmented stakeholder collaboration is another key issue. While game-theoretic models [64] [91] analyze interactions between manufacturers, recyclers, and policymakers, they often overlook consumer behavior and cross-sectoral partnerships. Furthermore, emerging recycling technologies such as hydrometallurgy [52] and pyrolysis [68] are frequently studied in isolation from infrastructure planning, creating a disconnect between technological advancements and their practical implementation.

To address these gaps, future research should focus on developing dynamic, hybrid decision-support systems that integrate real-time data analytics (e.g., IoT-enabled battery tracking [82]) with adaptive MCDM techniques. Resilience-optimized infrastructure design, incorporating climate risk assessments and decentralized preprocessing hubs [55] [62] [67] [70], could enhance system robustness. Policy-aware techno-economic models should also be prioritized to quantify how subsidies [62] and carbon pricing influence optimal facility locations. Advanced technologies, such as AI-driven predictive siting [29] and blockchain-enabled supply chain transparency [67], offer promising avenues for innovation. Additionally, holistic stakeholder engagement frameworks, co-designed with industry and communities, could improve equity and feasibility in site selection. Finally, harmonizing global sustainability metrics through open-access benchmarking platforms would enable more standardized evaluations of recycling networks. Moving forward, interdisciplinary collaboration will be essential to bridge these gaps. Combining engineering, data science, economics, and policy perspectives can help design EV battery recycling infrastructures that are not only sustainable but also adaptable to future technological and regulatory shifts. Key pathways include dynamic modeling (e.g., reinforcement learning-augmented MCDM [87]), resilience-enhanced planning (e.g., disaster recovery criteria [44]), and policy-integrated optimization (e.g., carbon tax simulations [54] [90]). By addressing these challenges, future research can pave the way for more efficient, scalable, and environmentally sound EV battery recycling systems. Recommended Pathways for Future Studies are shown in table 6.

Table 6 Recommended Pathways for Future Studies

Focus Area	Key Actions	Relevant Studies to Build Upon
Dynamic Modeling	Develop time-series MCDM with stochastic inputs.	[33], [47], [62]
Resilience Metrics	Add redundancy, disaster recovery, and adaptive capacity criteria.	[26], [44], [55]
Policy Integration	Model carbon taxes, subsidies, and cross-border regulations.	[62], [72], [87]
AI/ML Applications	Merge predictive analytics with GIS for real-time siting.	[29], [67], [88]
Stakeholder Synergy	Use game theory + surveys to optimize public-private partnerships.	[75], [79], [91]

VI. CONCLUSION

This systematic literature review provides a comprehensive synthesis of 69 academic studies that explore the intersection of sustainability evaluation and decision-making frameworks in EV battery recycling and EV charging station siting. The review reveals that methodological diversity, particularly through the use of MCDM approaches (e.g., AHP, TOPSIS, BWM, DEMATEL), GIS-based models, and hybrid frameworks, is a defining feature of current research. However, the extent to which sustainability dimensions, especially the social and technical criteria, are incorporated remains inconsistent across studies and geographies. In the EV battery recycling domain, research predominantly emphasizes environmental and economic aspects, with limited attention to reverse logistics network optimization and the full lifecycle implications of recycling strategies. Conversely, the EVCS siting literature is increasingly enriched by spatial analytics and real-time data integration, though often at the expense of comprehensive sustainability assessments. Across both domains, relatively few studies engage deeply with stakeholder perspectives, policy alignment, or circular economy frameworks. This review identifies critical gaps and offers several pathways for future inquiry. These include the need for, (i) integrated frameworks that combine LCA, techno-economic analysis, and policy scenarios, (ii) more robust incorporation of social equity and resilience criteria; and (iii) the adoption of adaptive, data-driven models for dynamic decision-making. By bridging conceptual and methodological insights, this review supports the development of sustainable and scalable EV infrastructure that aligns with broader decarbonization and mobility goals.

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- None

➢ *Declaration*

➢ *Conflict of Interest*

➢ *Compliance with Ethical Standards*

- *Disclosure of Potential Conflict of Interest:*

The authors declare that they have no potential conflict of interest.

- *Statement of Animal and Human Rights*

✓ *Ethical Approval*

All applicable institutional and/or national guidelines for the care and use of animals were followed.

✓ *Informed Consent*

For this type of analysis formal consent is not needed.

➢ *Author Contributions*

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➢ *Conflicts of Interest*

The authors declare that they have no potential conflict of interest.

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