INFRASTRUCTURE AND POLICY GOVERNANCE IN ELECTRIC VEHICLE BATTERY REVERSE LOGISTICS THROUGH A CIRCULAR ECONOMY PERFORMANCE PERSPECTIVE

INFRASTRUKTUR DAN TATA KELOLA KEBIJAKAN DALAM LOGISTIK BALIK BATERAI KENDARAAN LISTRIK MELALUI PERSPEKTIF KINERJA EKONOMI SIRKULAR

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A B S T R A C T
The accelerating growth of the electric vehicle (EV) market necessitates robust closed-loop supply chains (CLSC) to manage end-of-life batteries. However, the existing global literature remains significantly fragmented. This systematic review delivers an extensive diagnostic mapping of 33 influential studies to address three core research questions concerning network design, operational boundaries, and structural research gaps. The findings indicate that current scholarship is strongly polarized across three disconnected pillars: network configuration, operational uncertainty, and macro-level policy. Moreover, a persistent methodological divide separates micro-level operations research from macro-level behavioral frameworks. Physical network optimization models offer substantial spatial and logistical precision in facility allocation but continue to treat dynamic regulatory instruments as fixed, static constants. In contrast, macro-governance simulations and game-theoretic approaches capture policy volatility and multi-actor compliance elasticity, yet function within a spatial void, disregarding real-world multi-echelon capacity constraints and logistical bottlenecks. As a result, prevailing frameworks fail to assess how evolving governance mechanisms interact with finite logistical resources. This review establishes a vital academic rationale for future research trajectories aimed at bridging this sectoral divide. It emphasizes the urgent necessity of integrated architectures that directly connect dynamic macro-governance feedback systems with the spatially constrained physical boundaries of circular logistics networks.

Keywords:
Electric Vehicle Batteries; Closed-Loop Supply Chain; Systematic Literature Review; Circular Economy; Structural Polarization

A B S T R A K
Pertumbuhan pesat pasar kendaraan listrik menuntut adanya closed-loop supply chain (CLSC) yang kuat untuk mengelola baterai bekas. Namun, kajian global saat ini masih menunjukkan tingkat fragmentasi yang tinggi. Tinjauan pustaka sistematis ini menyajikan pemetaan diagnostik menyeluruh terhadap 33 studi utama untuk menjawab tiga pertanyaan penelitian kunci terkait konfigurasi jaringan, batasan operasional, dan celah struktural.
Hasil analisis menegaskan adanya polarisasi tajam dalam tiga pilar terpisah: konfigurasi jaringan, ketidakpastian operasional, dan kebijakan makro. Selain itu, terdapat jurang metodologis yang berkelanjutan antara riset operasional mikro dan kerangka perilaku makro. Model optimasi jaringan fisik menawarkan presisi tinggi dalam aspek spasial dan logistik, tetapi memperlakukan instrumen regulasi dinamis sebagai konstanta statis. Sebaliknya, simulasi tata kelola makro dan pendekatan teori permainan mampu menangkap fluktuasi kebijakan serta elastisitas kepatuhan multi-aktor, namun berjalan tanpa landasan spasial yang nyata, sehingga mengabaikan keterbatasan kapasitas fasilitas dan hambatan logistik. Akibatnya, kerangka kerja yang ada belum mampu menilai bagaimana perubahan mekanisme tata kelola berinteraksi dengan aset logistik yang terbatas. Tinjauan ini memberikan landasan akademik penting bagi arah penelitian masa depan untuk menjembatani polarisasi sektoral tersebut. Temuan ini menekankan kebutuhan mendesak akan arsitektur terpadu yang dapat menghubungkan umpan balik tata kelola makro yang dinamis secara langsung dengan batasan spasial dan fisik jaringan logistik sirkular.

Kata Kunci: Baterai Kendaraan Listrik; Rantai Pasok Loop Tertutup; Tinjauan Pustaka Sistematis; Ekonomi Sirkular; Polarisasi Struktural

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I. INTRODUCTION

The evaluation of circular economy (CE) performance within multi-echelon reverse logistics networks constitutes a key operational challenge for developing sustainable end-of-life (EOL) strategies of electric vehicle batteries (EVBs).

In modern industrial engineering, understanding reverse logistics requires a comprehensive integration of existing research. While many studies focus on specific network designs, uncertainty management, or policy evaluation, they often remain fragmented and disconnected. This creates a significant gap in how these elements fit together. Most studies focus on individual aspects such as closed-loop supply chain planning, uncertainty parameters, or policy impacts, often examined in isolation without an integrated framework. Consequently, there is no systematic approach to link these perspectives together. This research seeks to bridge that gap by performing a comprehensive review of reverse logistics studies, encompassing network configurations, uncertainty vectors, regulatory elements, and circular economy performance metrics. The objective is to develop an organized thematic mapping that clarifies existing knowledge and identifies future research priorities.

Extensive scholarly contributions have been reported in peer-reviewed studies to address diverse aspects of battery recovery networks. To provide a clear structural overview, these prior primary studies are categorized into four critical thematic streams. First, in relation to infrastructure design and facility location, earlier studies have largely applied spatial optimization models to manage the rising flow of end-of-life (EOL) batteries while ensuring global-scale material recovery [1]. At the same time, aligning supply chain profitability with strict emission reduction targets has been achieved through multi-objective optimization frameworks [2].

Second, concerning operational uncertainty and risk management, analytical approaches have advanced to address systemic disruptions by incorporating consumer engagement strategies combined with robust possibilistic programming to reduce variability in returns [3]. Moreover, as highlighted in [4], a two-stage stochastic model enhances strategic capacity allocation, while under unexpected facility failures, the use of Deep Reinforcement Learning demonstrates greater adaptability compared to traditional static optimization [5].

Third, shifting toward policy and regulatory frameworks, these institutional mechanisms exert a critical influence on supply chain behavior within governance structures. For example, prior research combined the Best–Worst Method with Radial Basis Function Neural Networks to predict thresholds of urban supply disruptions under sudden regulatory changes and macro-policy shifts [6].

Fourth, regarding stakeholder governance and incentive mechanisms, ecosystem resilience and end-of-life efficiency are reinforced through collaborative schemes and diagnostic integrations. A sustainable shared reverse logistics model has been proposed to collectively lower high infrastructure investment barriers among supply chain participants [7], while the involvement of Fourth-Party Logistics providers effectively reduces localized disruption risks through coordinated stakeholder collaboration [8].

Beyond spatial considerations, effective implementation requires recognition of systemic disruptions. Recent structural investigations [9] applied the TISM-MICMAC methodology to highlight 'market and social' together with 'policy and regulation' as dominant barriers obstructing reverse logistics. Within emerging industrial contexts, formal regulatory constraints and limited domestic recycling capabilities remain the primary inhibitors of circularity adoption [10]. To navigate these barriers during dynamic market transitions, [11] proposed an evolutionary analytical framework stressing that closed-loop supply chain (CLSC) design necessitates concurrent technological and product co-development. These challenges are even more acute in specialized domains; second-life battery supply chains face significant reverse logistics complexity due to input cell variability, requiring standardized performance testing prior to secondary market deployment [12]. To prevent reduced system resilienceat initial stages, the absence of early quality management must be addressed, as early digital testing has been shown to enhance downstream material value twofold [13].

Second, alternative research directions emphasize strategic business frameworks and institutional regulatory mechanisms to ensure stable material circulation. To enhance source-level collection efficiency, shifts in product ownership models have been proposed. As highlighted by [14] and confirmed by [15], a use-oriented Product-Service System (PSS) integrated with sharing economy principles significantly strengthens circular control by maintaining asset custody and enabling scheduled mass collection. In regional contexts, circularity is often constrained by costly upstream collection infrastructures rather than downstream recycling capacity [16], indicating that vertical integration between automotive manufacturers and recyclers [17] is crucial to avoid secondary processing collapse due to high logistics costs. For emerging economies, localized strategic pathways have been developed for Indonesian waste management firms [18], including foreign joint ventures, 3PL automotive collaborations, and specialized battery repair facilities.

To legally institutionalize recovery loops, pricing optimization frameworks and policy instruments must be embedded. System dynamics simulations [19] reveal that early-stage government price subsidies are more effective in stabilizing the second-use battery sector compared to downstream research incentives. Likewise, the interaction of subsidies and penalties strongly influences facility siting [20], while Extended Producer Responsibility (EPR) mandates enhance circular design efficiency and revenue-sharing contracts reduce channel conflicts to maximize CLSC profitability [21]. Regulatory integration has been extended by [22], demonstrating that cascade utilization substantially increases CLSC profitability, with EPR policies acting as catalysts for profit redistribution to secondary processors.

Moreover, given the involvement of multiple stakeholders, multi-actor coordination has been formalized through game-theoretic approaches. To optimize fund

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allocation under EPR mandates, [23] proposed an evolutionary game model transferring subsidies directly to primary collectors to ensure transparency, while simulation studies [24] found that recycling success depends on strict non-compliance penalties combined with dynamic incentives. Expanding behavioral dimensions, consumer trade-in schemes significantly improve returns, with reward-penalty mechanisms (RPM) outperforming direct subsidies [25]. Additionally, [26] showed that embedding carbon awareness into utility functions reshapes recycling pricing, making non-financial green recognition effective for accelerating reverse logistics. Addressing macroeconomic volatility, sustainability assessments [27] identified high sensitivity to virgin material price shocks, which can be anticipated using system dynamics. To mitigate environmental impacts under market constraints, Carbon Trading Schemes (CTS) integrated with advanced manufacturing technologies [28] reduce emissions while preserving profitability. Finally, to resolve incentive conflicts between manufacturers and recyclers under fuzzy information, [29] emphasized the necessity of flexible circular governance contracts, mathematically supported by a hybrid Grey Degree of Possibility in Game Theory [30] to secure equilibrium strategies with minimal risk.

Nevertheless, despite these important individual findings, a holistic resolution to the central issue has not been realized. The key limitation in current scholarship is that research directions remain highly fragmented. Studies focusing on physical layout optimization are conducted within static and deterministic settings, thereby overlooking real-world supply variability. In contrast, investigations into strategic regulations, pricing structures, and stakeholder dynamics (including EPR, PSS, and Game Theory) conceptualize logistics layouts merely as simplified abstractions. At present, there is a notable absence of an integrated framework capable of simultaneously capturing long-term circular economy outcomes and multi-echelon network allocations under conditions of supply constraint and escalating operational costs. As a result, existing literature does not yet offer a cohesive network architecture that can dynamically safeguard circular logistics systems against the highly uncertain disruptions of the battery market.

To address this foundational methodological gap, the present study introduces a multi-dimensional synthesis matrix that bridges the structural disconnection between physical reverse logistics optimization and macro-level policy evaluations. Unlike earlier literature reviews, this study introduces a multi-dimensional synthesis framework designed to systematically operationalize the research novelty. This framework explicitly integrates five interrelated analytical domains: (i) network design and facility location configurations, (ii) operational uncertainties and risks linked to battery degradation and supply fluctuations, (iii) institutional policies and regulations mechanisms shaping cross-border compliance, (iv) stakeholder involvement and incentives structures guiding collaborative supply chain practices, and (v) multidimensional circular economy indicators encompassing economic outcomes, material circularity, and environmental impacts (CO_2).

In clarifying boundary scope, this multi-dimensional synthesis framework explicitly covers the entire closed-loop value chain, incorporating second-life battery utilization, technical remanufacturing processes, critical material recovery, and final end-of-life disposal. By cross-analyzing these dimensions, the framework effectively reveals critical gaps and structural inconsistencies between physical infrastructure capacity and prevailing policy governance systems.

For the purpose of systematically addressing the identified knowledge gaps, this study applies a Systematic Literature Review (SLR) approach. The implementation of this review strictly follows the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. The operational framework, including bibliometric extraction, criteria for inclusion, and screening procedures, is explained in detail within the subsequent Research Methodology section.

To ensure a strong alignment between the study's title, overarching objectives, and analytical scope, this systematic review is organized around the following key research questions:

RQ1: How is the existing body of research on electric vehicle (EV) battery closed-loop supply chains systematically classified across network configurations, operational uncertainties, and macro-level policy instruments?

RQ2: What specific circular economy indicators and measurement approaches are identified in the primary literature to assess the effectiveness of EV battery reverse logistics systems?

RQ3: In what ways do the interactions among network structures, uncertainty factors, and regulatory frameworks influence the overall circular economy outcomes within the current research landscape?

By synthesizing empirical evidence to answer these three questions, this review systematically delineates the structural boundaries of contemporary models, mapping the precise requirements necessary to construct uncertainty-resilient closed-loop battery supply chain architectures.

II. RESEARCH METHODS

This This study systematically reviews and maps contemporary academic contributions on electric vehicle battery reverse logistics and closed-loop supply chain architectures published between 2021 and 2026. To ensure clarity, reproducibility, and methodological robustness, the research design adheres strictly to the PRISMA 2020 revised guidelines. The operational implementation of this Systematic Literature Review (SLR) is structured into four consecutive stages, each designed to filter relevant literature, assess recent developments, and identify quantitatively validated frameworks.

The literature retrieval was conducted using the Scopus database to capture high-impact international

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publications, restricted to peer-reviewed articles indexed in Q1 and Q2 quartiles to guarantee the robustness of primary sources. Following the initial extraction, a multi-stage screening procedure was applied in line with the PRISMA 2020 framework. This included the removal of duplicate records, title and abstract reviews, and full-text eligibility checks against predefined criteria. As a result, a refined set of consolidated primary articles was obtained for the multi-dimensional synthesis matrix analysis, forming the basis for identifying recent developments and validated frameworks.

2.1. Search Strategy and Bibliographic Data Collection

The Scopus database was utilized as the primary bibliographic repository, due to its extensive indexing of high-impact journals in engineering, operations research, and supply chain management. To ensure comprehensive coverage, the systematic query applied two alternative Boolean formulations within the TITLE-ABS-KEY fields, which generated two distinct datasets for analysis:

a. Dataset A (Comprehensive Query): "Electric vehicle batteries" AND "Reverse logistics" AND "Circular economy" AND "Performance"
b. Dataset B (Broad Query): ("EV battery" OR "Lithium-ion battery") AND ("Reverse logistics" OR "Closed-loop supply chain") AND ("Circular economy" OR "Sustainability") AND "Performance"

The search horizon was limited to June 2021–May 2026, ensuring inclusion of the most recent technological and modeling advancements during the peak of the global EV transition.

2.2. Inclusion and Exclusion Criteria

In ensuring high-quality, conceptually validated, and methodologically consistent outcomes, this study applied strict inclusion and exclusion criteria:

a. Source and Quality Baseline: Only peer-reviewed original articles published in Scopus-indexed Q1 and Q2 journals were included. This quartile restriction was designed to guarantee methodological rigor, data reliability, and theoretical validity, which are crucial given the complexity of EV battery recovery systems. Accordingly, conference papers, book chapters, editorials, dissertations, and narrative reviews were excluded.
b. Language and Access: Eligible studies were required to be full-text publications in English to maintain global academic comparability.
c. Methodological and Structural Focus: Selected articles had to address at least one of the core pillars of EV battery closed-loop supply chains, including network design (e.g., facility location, multi-echelon routing), uncertainty management (through mathematical optimization such as MILP, Game Theory, or System Dynamics), or macro-level policy analysis.
d. Scope Boundaries: Studies limited solely to micro-level chemical recycling, battery material testing, or laboratory engineering parameters without broader relevance to closed-loop supply chains, circular economy indicators, or network optimization were systematically excluded.

2.3. Screening and Selection Process (PRISMA Flow)

The selection procedure adhered to a multi-phase PRISMA protocol to refine the initial search results into the final set of articles, as systematically depicted in the PRISMA Flowchart (Figure 1). During the Identification stage, raw bibliographic records were collected using predefined Boolean queries in Scopus. In the Screening stage, automated deduplication was applied, followed by title-level evaluations under strict keyword criteria:

a. For Dataset A: Records were excluded if they were duplicates, narrowly focused on chemical or material processes, or lacked explicit title combinations such as "Battery/Batteries AND Logistics", "Battery/Batteries AND Circular", or "Battery/Batteries AND Reverse".
b. For Dataset B: Records were excluded if they were duplicates, concentrated on micro-level chemical/materials processes, or did not contain title combinations like "EV Battery/Batteries AND Reverse", "EV Battery/Batteries AND Closed-Loop", or "EV Battery/Batteries AND Sustainability".

In the Eligibility stage, records were further removed if published by non-reputable sources, classified as conference papers, or deemed out-of-scope during abstract review. Finally, a quality evaluation was conducted to exclude non-Q1 and non-Q2 indexed articles, eliminate overlapping duplicates between Dataset A and Dataset B, and remove narrative reviews. This process finalized a dataset of 33 peer-reviewed original research articles.

2.4. Data Extraction and Synthesis Procedures

The final collection of 33 articles was subsequently analyzed through a systematic coding framework across three interconnected dimensions to address the core research questions:

a. For RQ1 (Thematic Classification of Enablers): The data extraction process emphasized grouping the literature into three core pillars that drive closed-loop supply chains, namely physical network structures, types of operational uncertainties (such as variations in return volume and quality), and macro-level policy mechanisms.
b. For RQ2 (Circular Economy Indicators and Measurement): The coding procedure examined the performance metrics and measurement approaches reported in the primary literature, systematically organizing them into three principal domains: economic-logistics efficiency, material circularity indices, and environmental impact measures (including CO_2emissions).
c. For RQ3 (Synthesis Procedure for Sectoral Polarization and Operational Boundaries): This final extraction stage aims to chart the global academic divide by classifying the collection of articles into two principal categories: the Structural Optimization Stream (Pillar 1 & 2

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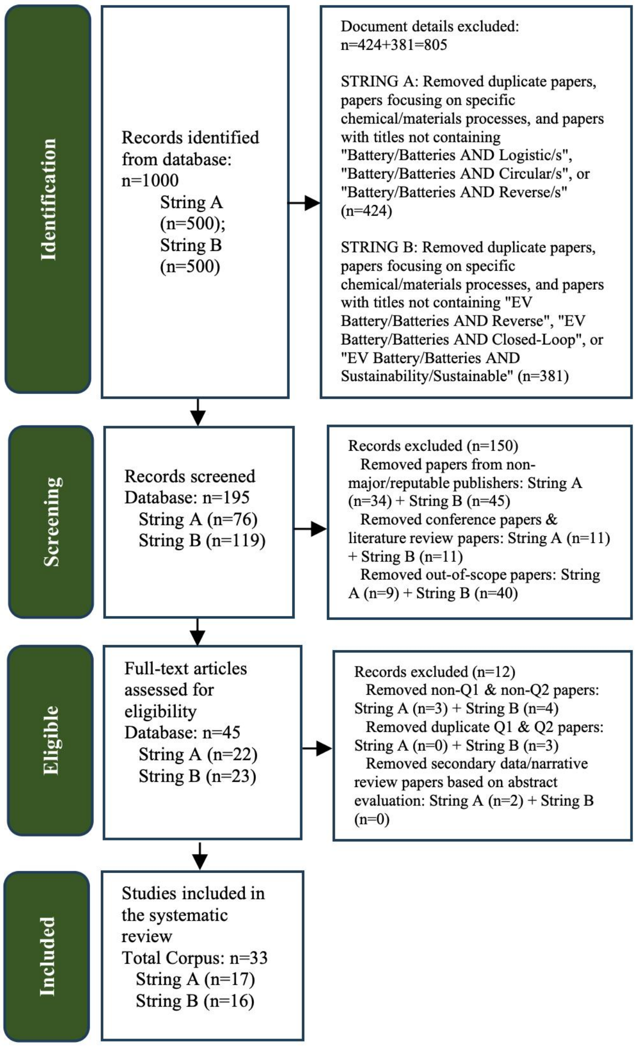
dominance) and the Behavioral Governance Stream (Pillar 3 dominance). The process methodically identifies the friction between their methodological orientations (mathematical optimization/ metaheuristics/DRL as opposed to game theory) and operational limits (strict physical constraints versus macro policy flexibility) to develop a comparative synthesis framework that reveals a clear research gap.



Source: Adapted from Page et al. (2021), synthesized from the literature corpus (2021–2026)

Figure 1. PRISMA 2020 Flow Diagram for The Systematic Literature Search and Multi-Stage Screening Process

III. RESULTS AND DISCUSSION

This chapter delivers a systematic and multi-dimensional examination of the 33 selected studies, aiming to comprehensively address the core research questions (RQ1, RQ2, and RQ3). Instead of simply restating data from summary tables, the discussion is organized into three progressive analytical stages.

First, Section 3.1 establishes a structural foundation by mapping research trends and proportional distribution across the key pillars of reverse logistics architecture. Second, Section 3.2 provides a cross-methodological evaluation, analyzing the trade-offs between deterministic and dynamic modeling approaches alongside circular economy indicators. Finally, Section 3.3 integrates these insights to propose a resilient governance and infrastructural framework specifically designed for the electric vehicle (EV) battery ecosystem.

3.1. Structural Mapping of Research Trends and Dimensional Proportions (RQ1)

This section focuses on addressing Research Question 1 (RQ1) by structurally mapping thematic patterns and dimensional configurations identified across the global body of literature. For a rigorous depiction of the current state of the art derived directly from core metadata, a structural synthesis checklist was applied across the 33 selected primary studies. Prior to executing the multi-dimensional classification, a comprehensive coding protocol was established to define the eligibility criteria for each analytical pillar.

A study was classified under a specific dimension if its title, keywords, abstract, or methodology explicitly aligned with the following operational definitions:

a. Network Configuration (Pillar 1): A study is included if it mathematically models or conceptually represents the physical structure of the reverse supply chain. This involves decisions on facility location, multi-echelon allocation, routing optimization, or spatial design of collection, testing, remanufacturing, and recycling centers.
b. Operational Uncertainties (Pillar 2): A study is included if it systematically integrates non-deterministic parameters inherent to the battery life cycle. This covers variations in return volumes, supply timing, unpredictable state-of-health (SoH) or degradation levels, price fluctuations, or facility disruption risks, often addressed using stochastic programming, robust optimization, or fuzzy logic.
c. Macro-level Policy (Pillar 3): A study is included if it evaluates governance mechanisms, regulatory frameworks, or financial instruments shaping the circular ecosystem. This encompasses mandates such as Extended Producer Responsibility (EPR), deposit-refund systems, carbon taxation, government subsidies, or penalty schemes influencing supply chain actors.
d. Methodological Approach: Beyond the three pillars, each study is cross-classified by its mathematical modeling, simulation techniques, or algorithmic frameworks used to resolve supply chain optimization or behavioral challenges.

Applying these transparent and rigorous criteria, a systematic mapping of the 33 studies was conducted, revealing structural intersections, notable imbalances, and thematic fragmentation in the literature. By tracing the

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cross-sections between the three pillars and methodological approaches, this classification highlights a critical gap where infrastructure planning often fails to evolve in tandem with regulatory dynamics. For a more granular evaluation, the 33 studies are analyzed chronologically and thematically across three progressive batches (see Table III.3.1, Table III.3.2, and Table III.3.3), illustrating how the literature has become structurally fragmented over time.

TABEL III.1.1
LITERATURE CLASSIFICATION MATRIX FOR INITIAL STREAM
(BATCH A1-A10)

Code	Paper Title & Author	Pilar 1	Pilar 2	Pilar 3	Quantitative Approach / Specific Methodology
A1	*Electric vehicles lithium-ion batteries reverse logistics implementation barriers analysis: a TISM-MICMAC approach* [9]	X	X	✓	Total Interpretive Structural Modeling (TISM) & MICMAC (Policy/Governance Barrier Analysis)
A2	*Designing a circular supply chain network for electric vehicle batteries: An improved robust possibilistic programming approach* [31]	✓	✓	X	Bi-objective Robust Possibilistic Programming (RPP), Non-Linear Model Linearization, AUGMECON Method
A3	*Strategic closed-loop supply chain configuration in the transition towards the circular economy of EV batteries: an evolutionary analytical framework* [11]	✓	✓	X	Evolutionary Analytical Framework (Multi-layer Dynamic Complexities)
A4	*Circular economy strategy for waste management companies of electric vehicle batteries in Indonesia* [18]	X	X	✓	Qualitative Descriptive Analysis (Waste Management Strategy Formulation)
A5	*Designing a reverse logistics network for electric vehicle battery collection, remanufacturing, and recycling* [1]	✓	X	✓	Dynamic Material Flow Analysis (3-parameter Weibull distribution), Facility Location Modeling (Horizon up to 2040) & Carbon Emissions
A6	*Integrating Efficiency and Priority in Circular Energy Supply Chains: A DEA-Informed BWM Analysis of Second-Life EV Battery Ecosystems in Emerging Economies* [32]	✓	X	X	Integrated Best-Worst Method (BWM) and Data Envelopment Analysis (DEA) (Ecosystem Prioritization)
A7	*Optimizing Reverse Logistics Network for Waste Electric Vehicle Batteries: The Impact Analysis of Chinese Government Subsidies and Penalties* [20]	✓	✓	✓	Two-Stage Stochastic Programming formulated into Mixed-Integer Linear Programming (MILP), SRDBH Heuristic Algorithm
A8	*Optimizing Sustainable and Resilient Electric Vehicle Battery Recycling Network: Insights from Fourth-Party Logistics* [8]	✓	✓	X	Resilient Network Modeling (EVBRND) with Heuristic Algorithms under Facility Disruption Risks (4PL)
A9	*Managing Strategic Interactions for a Circular Economy: An Evolutionary Game Analysis of a Dynamic Deposit-Refund System in Electric Vehicle Battery Recycling* [33]	X	✓	✓	Evolutionary Game Theory (EGT) & System Dynamics (SD) Simulation (EPR & Deposit-Refund System Analysis)
A10	*The sustainable shared reverse logistics framework: A blueprint for EV battery recovery* [7]	✓	X	X	Qualitative/Conceptual Framework (Shared Reverse Logistics & Sharing Economy)

Source: Primary Data Synthesis from Literature Extraction Metadata (2026)

Methodological and Pillar Analysis for Batch 1

The structural examination of the first evaluation batch reveals a strong foundational dependence on basic facility location planning (Pillar 1). From a methodological perspective, this stream is predominantly characterized by conventional deterministic mathematical programming (including linear and integer programming).

The key limitation of this approach lies in its inflexible operational assumptions; parameters are treated as static values. As a result, the models exclude volatile regulatory dynamics (Pillar 3) and operational variability (Pillar 2). This indicates that early research conceptualized reverse logistics primarily as a static, cost-oriented facility allocation exercise, thereby establishing the initial roots of methodological isolation within closed-loop supply chain scholarship.

TABEL III.1.2
LITERATURE CLASSIFICATION MATRIX FOR INTERMEDIATE STREAM
(BATCH A11-B3)

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Code	Paper Title & Author	Pilar 1	Pilar 2	Pilar 3	Quantitative Approach / Specific Methodology
A11	*Analysis of barriers to the implementation of circular economy in an Indian electric vehicle batteries manufacturer* [10]	X	X	✓	Qualitative/Descriptive Barrier Analysis (Identification of Potential Barriers for CE)
A12	*Managing structural tensions in the transition to the circular economy: the case of electric vehicle batteries* [29]	X	X	✓	Industrial Transition Analysis (Structural Tensions and Industrial Transition)
A13	*Life after use: circular supply chains for second-life of electric vehicle batteries* [12]	✓	X	X	Longitudinal Case Study (Mapping of applications, customer segments, actors, and supply chain activities)
A14	*The Technology Valley of Death of Circular Economy Solutions: A System Dynamics Simulation of Business Strategies for the Second-Use Battery Industry* [19]	X	✓	X	System Dynamics (SD) Simulation (Simulation of Business Strategies & Market Battery Price Trends)
A15	*Risk assessment in lithium-ion battery circular economy in sustainable supply chain in automotive industry using gray degree of possibility in game theory and MCDM* [30]	X	✓	X	Integration of Game Theory and Multi-Criteria Decision Making (MCDM) with Gray Degree of Possibility (Risk Assessment)
A16	*The circular economy of electric vehicle batteries: a Finnish case study* [16]	✓	X	X	Shared Reverse Logistics (SRL) Business Model analyzed through three design cycles (relevance, rigor, design)
A17	*Promoting circular systems in electric vehicle batteries: A use-oriented business model with sharing economy and reverse logistics integration* [14]	✓	X	X	Use-Oriented Product-Service System (PSS) Analysis integrated with Sharing Economy principles
B1	*Optimization of Lithium-Ion Battery Circular Economy in Electric Vehicles in Sustainable Supply Chain* [2]	X	✓	X	Gray Multi-Criteria Decision Making (Gray MCDM) (Barrier Management Analysis)
B2	*AI-Driven Resilient Reverse Logistics Network for Electric Vehicle Battery Circular Economy: A Deep Reinforcement Learning Approach with Multi-Objective Optimization Under Disruption Uncertainty* [5]	✓	✓	X	Bi-level optimization model coupled with Deep Reinforcement Learning (DRL - PPO), Fuzzy-Robust Stochastic programming with CVaR, and NSGA-III (Mitigating Disruption Uncertainty)
B3	*A two-stage stochastic model for sustainable and resilient closed-loop supply chain of electric vehicle batteries* [4]	✓	✓	X	Progressive three-tier modeling framework (Deterministic →Stochastic →Resilient), Two-stage stochastic programming

Source: Primary Data Synthesis from Literature Extraction Metadata (2026)

Methodological and Pillar Analysis for Batch 2

The second evaluation batch highlights a distinct progression toward advanced algorithmic sophistication in addressing real-world disruptions (Pillar 2). From a methodological standpoint, this cluster shifts away from deterministic models, incorporating Stochastic Programming, Robust Optimization, and emerging Artificial Intelligence paradigms (such as Deep Reinforcement Learning and Neural Networks).

This methodological evolution enables models to mathematically hedge against fluctuating battery return rates and complex material degradation scenarios. Nevertheless, a notable structural misalignment remains: despite their high mathematical rigor, these advanced optimization techniques continue to treat macro-level regulations (Pillar 3) as static external inputs rather than dynamic feedback mechanisms. This persistent separation further amplifies the gap between algorithmic capacity planning and volatile policy enforcement.

TABEL III.1.3
LITERATURE CLASSIFICATION MATRIX FOR CONTEMPORARY STREAM (BATCH B4-B16)

Code	Paper Title & Author	Pilar 1	Pilar 2	Pilar 3	Quantitative Approach / Specific Methodology
B4	*Research on power battery recycling in the green closed-loop*	X	X	✓	Integrated Grey Delphi-DEMATEL-ANP combined

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	supply chain: An evolutionary game-theoretic analysis [24]				with Grey Degree of Possibility and Zero-sum Game Theory
B5	*Sustainability of lithium-ion battery recycling industry in China: An explorative analysis via an innovative dynamic business modeling for sustainability* [27]	✓	X	✓	Dynamic Business Modeling for Sustainability (Systems/Scenario-based Approach)
B6	*Optimal decisions of closed-loop electric vehicle batteries supply chains under extended producer responsibility policies* [21]	X	X	✓	Integrated Grey Multi-Criteria Decision Making (Grey Delphi, Grey DEMATEL, Grey ANP) with Grey Possibility Degree
B7	*New energy vehicle battery recycling strategy considering carbon emotion from a closed-loop supply chain perspective* [26]	X	X	✓	Rank-dependent Expected Utility Theory combined with Evolutionary Game Theory (EGT)
B8	*Transition towards a sustainable circular battery business ecosystem: quality management principles impacting the value chain* [13]	✓	✓	X	Ecosystem Quality Management Framework (Quality Management & Multi-uncertainties Analysis)
B9	*Decisions for power battery closed-loop supply chain: Cascade utilization and extended producer responsibility* [22]	X	X	✓	Game-theoretic Modeling (Pricing Decision Models under EPR benchmarks)
B10	*A forewarning model for the reverse supply chain of urban End-of-Life power batteries based on a mix method of BWM and RBFNN* [6]	✓	✓	X	Hybrid Best-Worst Method (BWM) and Radial Basis Function Neural Network (RBFNN) via multi-modal data fusion forewarning model
B11	*Recycling mode selection for the reverse supply chain of waste power batteries: An environmental responsibility perspective* [34]	X	X	✓	Reverse Logistics Mode Selection Modeling (Optimal Recycling Mode Selection)
B12	*Research on closed-loop supply chain decision-making of power battery echelon utilization under the scenario of trade-in* [25]	X	X	✓	Supply Chain Decision-making Analysis under 3 Governance Policies (no subsidies, subsidies, rewards-punishments)
B13	*Design and assessment of sustainable spent automobile lithium-ion battery industries in Japan: A system dynamic business model approach* [17]	✓	X	✓	System Dynamics (SD) Business Model Approach (Economic & Regulatory Feasibility Study)
B14	*Research on closed-loop supply chain decision making of power battery considering subsidy transfer under EPR system* [23]	X	X	✓	Game Theory / Stackelberg Game Theory under the umbrella of EPR System & Subsidy Transfer
B15	*Effect of carbon trading scheme and technological advancement on the decision-making of power battery closed-loop supply chain* [28]	X	X	✓	Game Theory Framework integrated with Carbon Trading policy schemes
B16	*LRP-based design of sustainable recycling network for electric vehicle batteries*[15]	✓	✓	X	Location-Routing Problem (LRP) Modeling for performance degradation mitigation

Source: Primary Data Synthesis from Literature Extraction Metadata (2026)

Methodological and Pillar Analysis for Batch 3

The final evaluation batch underscores a pronounced sectoral and methodological polarization within contemporary scholarship. This group shifts the research emphasis toward strategic policy simulations and dynamic governance structures (Pillar 3). From a methodological perspective, this stream is largely dominated by decentralized behavioral frameworks, particularly Stackelberg and Evolutionary Game Theory.

Analysis of the abstracts reveals a significant structural fragmentation resulting from this methodological orientation: these game-theoretic applications exhibit a high degree of physical abstraction. Although effective in computing competitive market equilibria, subsidies, and penalty frictions, they consistently neglect multi-echelon facility layout constraints (Pillar 1) and network capacity limitations. Such models mathematically assume that regulatory equilibria will inherently resolve spatial logistics bottlenecks.

Consequently, the literature remains polarized between two methodological extremes: exact mathematical optimization, which plans infrastructure without policy adaptability, and game-theoretic models, which simulate policy dynamics without incorporating physical network realism.

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3.2 Conceptual Framework and Operational Boundaries of CE Performance (RQ2)

This section is dedicated to answering Research Question 2 (RQ2) by constructing a conceptual framework and evaluating the operational boundaries that govern Circular Economy (CE) metrics and indicators within the reviewed models. While Section 3.1 outlined the structural proportions of the literature to address RQ1, this section critiques how different modeling methodologies operationalize CE boundaries.

To establish a solid and consistent modeling within Indonesia's closed-loop electric vehicle (EV) battery supply chain must be clearly articulated. Instead of viewing circularity as a single abstract dimension, this study systematically disaggregates performance indicators into three interconnected operational domains, synthesized from the existing body of literature:
1. Economic-Logistical Performance: This domain assesses system-wide cost structures and the financial viability of the closed loop. It emphasizes manufacturing cost reductions, mitigation of international price fluctuations for critical materials, specific expenses related to battery handling and transportation, management of highly uncertain return volumes, and the design of cost-and-risk-sharing mechanisms among supply chain actors.
2. Material-Technical Circularity Performance: This domain evaluates physical and operational efficiency in extending battery lifespans across the circular economy hierarchy (5R/6R principles). It monitors recovery and utilization rates in second-life applications, repurposing, remanufacturing, and industrial-scale recycling, while also considering physical limitations such as battery degradation (*State of Health*) and the quality assurance of recycled outputs.
3. Environmental & Governance Performance: This domain tracks ecological impacts and regulatory compliance within the closed-loop system. It includes targets for carbon emission (CO_2) reduction, mitigation of hazardous chemical pollution across soil, water, and air, strict adherence to international transport standards, and enforcement of Extended Producer Responsibility (EPR) mandates supported by governmental frameworks.

These boundaries and parameters are comprehensively structured to safeguard the continuity of the model and ensure alignment with industrial engineering principles during subsequent simulation and analysis phases.

TABEL III.2.1
OPERATIONAL DOMAINS AND PARAMETERS OF CIRCULAR ECONOMY PERFORMANCE

Core Domain	Operational Parameter / Indicator	Contextual Scope & Constraints	Literature Support
Economic-Logistical	1. Manufacturing cost reduction 2. International market price volatility mitigation 3. Specialized battery-handling & transport costs 4. Management of unpredictable return volumes 5. Profit-and-risk-sharing configuration	Evaluates the systemic cost structures, supply security, and financial viability of the closed-loop network.	[10][18][33][30]
Material-Technical	1. 5R/6R hierarchy efficiency rates 2. Second-life & repurposing recovery volume 3. Industrial-scale recycling capability 4. Battery degradation limits (*State of Health*) 5. Quality assurance of recycled outputs	Measures the physical and operational efficiency of battery lifespan extension pathways and mineral recovery.	[18][10][30][33]
Environmental & Governance	1. Carbon emission (CO_2) reduction targets 2. Toxic hazardous waste mitigation (soil, water, air) 3. Extended Producer Responsibility (EPR) compliance 4. Policy and support program alignment	Monitors ecological impacts, regulatory compliance, and institutional support for the circular ecosystem.	[18][10][30][33]

Source: Synthesized by The Authors from The Literature Analysis (2026)

3.3 Integrative Synthesis Framework and Strategic Implications for EV Battery Circular Networks

This section delivers the final analytical synthesis to address Research Question 3 (RQ3) by integrating the systemic gaps identified in the literature and proposing a multi-dimensional conceptual trajectory.
Drawing on the multi-dimensional mapping in Section 3.1 (RQ1) and the operational boundaries examined in Section 3.2 (RQ2), a critical synthesis is presented to evaluate how future research can strengthen EV battery reverse logistics against volatile market disruptions.

TABEL III.3.1
SYNTHESIS MATRIX OF SECTORAL POLARIZATION AND OPERATIONAL BOUNDARIES

Evaluation Dimension	**The Structural Optimization Stream (Pillar 1 & 2 Dominance)**	**The Behavioral Governance Stream (Pillar 3 Dominance)**
Associated Papers (Total N=33)	A2, A3, A5, A6, A7, A8, A10, A13, A16, A17, B1, B2, B3, B8, B10, B13, B16	A1, A4, A9, A11, A12, A14, A15, B4, B5, B6, B7, B9, B11, B12, B14, B15
Methodological Focus	Exact Mathematical Optimization, Metaheuristics, and Deep Reinforcement	Game Theory (Stackelberg/Evolutionary) and Qualitative Barrier Analysis.

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	Learning.	
Operational Boundary	High physical/spatial constraints; static and rigid policy inputs.	High policy dynamic/compliance elasticity; highly abstracted spatial logistics.

Source: Synthesized by The Authors from The Literature Analysis (2026)

The integration examined in Table 3.3.1 reveals a fundamental structural polarization within current scholarship, defining the main research gaps as follows:

1. Physical-Optimization Blindness to Policy Dynamics Quantitative models in the optimization stream deliver strong operational rigor in relation to facility locations, network dimensions, and transport costs. Yet, they treat governance frameworks, financial incentives, and regulatory mandates as static inputs, failing to reflect how policy shifts reshape actor behavior over time.
2. Behavioral Framework Blindness to Spatial Capacity In contrast, models within the behavioral governance stream excel at simulating macro-level policy interventions and multi-actor compliance dynamics. However, they operate without spatial grounding, assuming that regulatory equilibria will automatically resolve reverse logistics challenges while ignoring facility capacity bottlenecks and geographical constraints.

IV. Conclusion

This systematic literature review delivers a comprehensive diagnostic mapping and structural synthesis of current research on electric vehicle battery (EVB) closed-loop supply chains, explicitly addressing the three central research questions. Regarding RQ1, the literature reveals structural fragmentation across 33 global studies, concentrated within three distinct pillars (Network Configuration, Operational Uncertainty, and Macro-level Policy). Although methodological approaches are evolving toward advanced mathematical programming and algorithmic intelligence, they remain confined within individual pillars rather than achieving genuine interdisciplinary integration.

Regarding RQ2, the assessment of operational boundaries confirms that existing performance metrics are narrowly defined. Models are polarized in their system definitions—either focusing exclusively on micro-level material circularity (e.g., NMC vs. LFP degradation) and carbon footprints, or emphasizing regulatory compliance elasticity—without merging these operational layers into a unified evaluation framework. Regarding RQ3, the synthesis identifies a persistent methodological divide in global scholarship. Macro-level behavioral models overlook physical facility allocation and capacity constraints, while micro-level spatial optimization frameworks treat regulatory policy shifts as static constants.

As a result, this review establishes a critical academic rationale for future research trajectories aimed at overcoming sectoral polarization. The prevailing gap in global scholarship underscores the need for unified frameworks that directly connect dynamic macro-level governance feedback mechanisms with the finite, real-world physical capacities of multi-echelon logistics networks.

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