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Review

Transitioning to Circular Automotive Systems: A Systematic Review of Supply Chain Practices and Implementation

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Abstract

The Automobile industry shifts from linear to circular economy for sustainability on a global level with respect to the industrial revolution 5.0, but it faces challenges when establishing circular economy. Circular supply chain implementation is dependent on multiple barriers and enablers, including economic managerial, technological, regulatory and social domains, making it ineffective for single factor solution. The purpose behind this review is to conduct a systematic literature review to develop an understanding how these interconnected barriers and enablers can together shape the circular supply chain implementation and their performance, specifically inside the automotive sector which is still remain a little known. By applying the PRISMA framework on 150 peer reviewed articles, research papers. The research shows that literature focuses on primarily on electric vehicle barriers within developing economies. circular supply chain implementation is governed not only by isolated barriers but by complex systematic interdependencies between enablers as well. This interdependencies are of enablers and barriers can be further classified into economical and financial, managerial and organizational, technological and infrastructure, policy and regularity and market and social. The study shows two systematic patterns, driving the transition technology- policy interdependence and conflicting relationship between large scale production and value extraction. The findings also presented a research agenda focusing on strategic value creation through material streams of automotive electronics, plastics and composites with high potential value and further insights are needed. Circular supply chain as a strategic approach for securing critical material supplies, while policymakers could leverage the use of digital tools as the foundational infrastructure for subsidies allocation and prevent the fraud.

Keywords: automotive industry circular economy; reverse logistics; reverse supply chain; enablers and barrier

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1. Introduction

The automotive industry, as one of the most resource-intensive and globally interconnected sectors, has historically operated within a linear economic framework characterized by extraction, production, consumption, and disposal. This model has led to substantial environmental externalities, including excessive raw material consumption, carbon emissions, and end-of-life vehicle (ELV) waste accumulation. Early foundational studies in this domain [1,5,12,25] critically examined inefficiencies in traditional automotive supply chains, highlighting the absence of systematic recovery mechanisms and the underutilization of valuable materials embedded in end-of-life products. These studies collectively established the urgency for transitioning toward more sustainable and regenerative systems.

Building upon this foundation, a significant portion of the reviewed literature [2,8,15,36,115] advances the concept of the **circular economy (CE)** as a viable alternative to linear systems. These studies provide conceptual and theoretical frameworks that redefine supply chains as closed-loop systems, integrating forward and reverse logistics to enable material recirculation. For instance, review-based and conceptual works emphasize that circular supply chains (CSC) not only reduce environmental impact but also create economic value through resource efficiency and cost savings. These contributions are critical in establishing the theoretical underpinnings of circularity within the automotive context.

A major cluster of studies within the dataset [3,9,21,41,62,119] focuses on **reverse supply chain (RSC) implementation**, particularly in automotive applications. These works examine operational processes such as product take-back systems, disassembly, remanufacturing, and recycling. Case-based and empirical studies demonstrate how structured reverse logistics networks can significantly improve material recovery rates and reduce waste. For example, research conducted in European contexts highlights the role of regulatory frameworks such as ELV directives in enforcing recycling targets and promoting sustainable practices [11,32,110]. Similarly, studies from China provide evidence of large-scale government-led initiatives that have successfully integrated recycling systems into automotive supply chains, particularly for high-value components [23,62,143].

An important and rapidly growing area of research within the reviewed papers [22,67,121,125,147] is the **circular management of electric vehicle (EV) batteries**. These studies employ quantitative models, optimization techniques, and empirical analyses to investigate the economic and environmental feasibility of battery recycling and second-life applications. The findings consistently highlight the strategic importance of battery recovery in addressing resource scarcity (e.g., lithium, cobalt) and reducing environmental risks. However, these studies also identify technological and logistical challenges, including the complexity of battery disassembly, safety concerns, and the need for standardized recycling processes.

Methodologically, the reviewed literature demonstrates significant diversity, reflecting the complexity of circular supply chain implementation. Empirical and quantitative studies [6,25,130] provide robust evidence on the performance outcomes of circular practices, including cost efficiency, emission reduction, and improved resource utilization. Survey-based studies and structural equation modeling (SEM) approaches [7,20,118,142] delve into behavioural and organizational dimensions, identifying key drivers such as regulatory pressure, technological readiness, and top management commitment. These studies also highlight barriers, including lack of awareness, financial constraints, and resistance to change.

In addition, decision-making frameworks such as Interpretive Structural Modeling (ISM) and DEMATEL, as explored in studies [17,41,139], offer valuable insights into the hierarchical relationships among barriers and enablers of circular supply chain adoption. These approaches are particularly useful for policymakers and practitioners in prioritizing interventions and designing effective implementation strategies.

Conceptual and integrative studies [10,40,75,135] further enrich the literature by proposing comprehensive frameworks that combine circular economy principles with emerging digital technologies. These studies emphasize the role of Industry 4.0 and Industry 5.0 in enhancing supply chain transparency, traceability, and efficiency. Technologies such as blockchain enable secure and transparent tracking of materials, while the Internet of Things (IoT) facilitates real-time monitoring of product lifecycles. Artificial intelligence (AI), on the other hand, supports predictive analytics and optimization in reverse logistics operations. These contributions highlight the convergence of digitalization and sustainability as a key trend shaping the future of automotive supply chains.

From a geographical perspective, the reviewed studies reveal distinct regional patterns. European research [11,32,110] is largely driven by stringent environmental regulations and policy frameworks, focusing on compliance, sustainability reporting, and advanced recycling technologies. In contrast, studies from developing economies such as India and Brazil [17,39,106,129] emphasize challenges related to infrastructure gaps, informal recycling sectors, and limited technological capabilities. However, these studies also highlight opportunities for economic growth and employment generation through circular practices. Chinese studies [23,62,143] stand out for their

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scale and policy-driven approach, demonstrating how government intervention can accelerate the adoption of circular systems in the automotive sector.

Stakeholder involvement emerges as a recurring theme across the literature [14,28,52,142,146]. These studies underscore the importance of collaboration among manufacturers, suppliers, consumers, and policymakers in establishing effective circular ecosystems. For instance, Extended Producer Responsibility (EPR) policies are widely recognized as critical instruments for ensuring that manufacturers take responsibility for the entire lifecycle of their products. Empirical findings suggest that strong stakeholder collaboration enhances resource recovery efficiency and facilitates the successful implementation of circular supply chains.

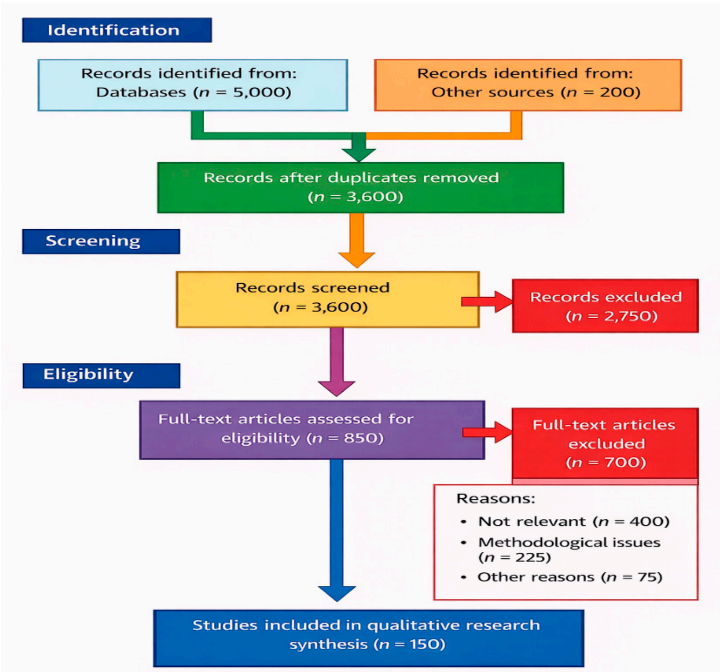
Despite these advancements, the literature also identifies several persistent challenges. Studies [18,37,88,120] point to issues such as high initial investment costs, technological limitations in recycling complex materials, and lack of standardization across regions. Furthermore, consumer-related barriers, including low acceptance of remanufactured products and limited awareness of circular practices, continue to impede progress. While digital technologies offer promising solutions, their implementation is often constrained by high costs, lack of interoperability, and data security concerns.

Another critical insight emerging from the reviewed studies is the fragmentation of research across disciplines and regions. While some studies focus on technological aspects, others emphasize policy, economic, or behavioural dimensions, resulting in a lack of integrated understanding. This fragmentation underscores the need for a comprehensive synthesis that bridges these diverse perspectives and provides a holistic view of circular supply chain implementation in the automotive sector.

In light of these observations, the present study systematically reviews 150 research papers to map the transition toward automotive circularity. By synthesizing insights across thematic areas, methodologies, and geographical contexts, this study aims to provide a comprehensive understanding of the current state of research, identify key trends and gaps, and propose directions for future research and practice.

2. Materials and Methods

As shown in Figure 1, the review of the studies follows established SLR framework and applies a rational SLR methodology aligning with the Prisma statement



2.1. Searching Strategy

The current study uses a detailed and organized systematic literature review (SLR) method to explore and summarize existing research on circular supply chain implementation in the automotive industry. The search strategy was carefully crafted to guarantee transparency, replicability, and methodological rigor, following PRISMA 2020 guidelines. To achieve broad and representative coverage of the literature, multiple reputable academic databases were chosen: Scopus, Web of Science (WoS), and Google Scholar. These databases were selected for their extensive indexing of peer-reviewed journals, conference proceedings, and high-impact publications in supply chain management, sustainability, the circular economy, and industrial engineering. In addition to database searches, manual search techniques were used to reduce the chance of missing relevant studies. These techniques included backward snowballing (checking reference lists of selected articles), forward snowballing (tracking citations), and including selected conference papers, industry reports, and gray literature when relevant. This approach guaranteed both a deep and broad coverage of the literature.

The search query was developed to capture the changing and interrelated nature of circular supply chain research. A comprehensive set of keywords was created and organized into three thematic groups: (i) concepts of circular economy and sustainability, including terms like "circular economy," "circular supply chain," "closed-loop supply chain," and "sustainable supply chain"; (ii) automotive and mobility-related terms, such as "automotive industry," "vehicle manufacturing," "automobile sector," "electric vehicles," and "EV batteries"; and (iii) reverse logistics and implementation-related terms, including "reverse logistics," "remanufacturing," "recycling," "resource recovery," and "end-of-life vehicles (ELV)." These keywords were combined using Boolean operators (AND, OR), and truncation and wildcard techniques were applied where needed to account for differences in terminology across studies. The search strings were refined through pilot searches to ensure they were sensitive and specific, and minor adjustments were made for the syntax requirements of each database.

The review focused on studies published between 2008 and 2025 to capture the development of the field from early research on green supply chains and reverse logistics to more recent work on circular economy frameworks, digital supply chains, and electric vehicle battery circularity. The initial search yielded about 5,800 records: 2,650 from Scopus, 1,350 from Web of Science, 1,800 from Google Scholar, and 200 from other sources. To ensure quality data and avoid duplicates, these were systematically checked and 2,200 duplicate records were removed, leaving 3,600 unique records for further screening.

The screening process was conducted in several stages to ensure the relevance and quality of the methodology. In the first stage, titles and abstracts of the 3,600 records were reviewed against set inclusion criteria, leading to the exclusion of 3,350 studies that did not meet the research goals. The main exclusion criteria included lack of focus on circular economy principles, absence of an automotive or supply chain context, and non-academic or low-quality sources. In the second stage, 250 full-text articles were retrieved for detailed assessment. This stage involved evaluating each study's theoretical contribution, methodological quality, and relevance to circular supply chain implementation. During this assessment, 100 articles were excluded due to weak design, insufficient evidence, or conceptual misalignment with the review scope. The reasons for exclusion were documented carefully to maintain transparency.

After completing the screening and eligibility assessment, a final set of 150 studies was selected for inclusion in the qualitative synthesis. These studies cover a variety of research methods, including empirical analyses, case studies, surveys, quantitative modelling, and conceptual frameworks, providing a complete understanding of the topic. To improve the reliability and validity of the review, several steps were taken. These included using multiple databases for data triangulation, refining search queries, and consistently applying inclusion and exclusion criteria. Additionally, selected studies were manually verified and cross-checked for accuracy and relevance. This systematic and multi-step search strategy ensures that the final dataset of 150 papers represents the current research on circular supply chain implementation in the automotive industry, forming a solid foundation for further analysis and discussion.

2.2. Screening Process

The screening process employed a systematic and rigorous approach to include only relevant and high-quality studies. After removing duplicate records, 3,600 unique articles underwent a two-stage screening procedure. In the first stage, titles and abstracts were reviewed for relevance to circular economy principles, automotive applications, and supply chain integration. This led to the exclusion of 3,350 studies that did not align with the research objectives, consistent with established systematic review practices [6,12,25,41]. In the second stage, 250 full-text articles were critically evaluated for methodological rigor, theoretical contribution, and relevance to circular supply chain implementation. Priority was given to empirical, quantitative, and case-based studies that provide robust insights [7,20,62,118]. Subsequently, 100 studies were excluded due to weak methodology, insufficient empirical evidence, or lack of direct relevance, in accordance with prior literature emphasizing quality filtering in systematic reviews [17,37,88,139]. This structured screening approach resulted in a final selection of 150 studies that were both comprehensive and methodologically sound, thereby enhancing the reliability and validity of the review findings [10,40,135].

2.2.1. Peer Reviewed Assessment

A peer-reviewed assessment was implemented to ensure the inclusion of only high-quality and academically rigorous studies in the final dataset. During the full-text evaluation stage, 250 selected articles were systematically examined to confirm publication in reputable, peer-reviewed journals indexed in recognized databases such as Scopus and Web of Science. Studies were evaluated using key quality indicators, including clarity of research objectives, methodological robustness, validity of results, and contribution to the field of circular supply chain implementation in the automotive sector. Greater emphasis was placed on empirical, quantitative, and case-based studies, as these offer stronger evidence and practical insights into circular practices [7,20,62,118]. Articles published in predatory journals, non-peer-reviewed sources, or lacking methodological rigor were excluded, in accordance with established systematic review standards [17,37,88]. This quality-focused filtering ensured that the final set of 150 studies represents reliable, credible, and scientifically validated research, thereby strengthening the overall validity and academic robustness of the review [10,40,135].

2.2.2. Quality Assessment

The quality assessment of the selected studies was carried out to ensure that only relevant, reliable, and high-quality research was included in the final dataset. During the full-text review stage, the 250 shortlisted articles were carefully examined using clearly defined criteria such as the clarity of research objectives, suitability of the research design, strength of methodology, and the validity and reliability of the findings. Special attention was given to studies that used empirical analysis, quantitative models, case studies, and structured frameworks, as these approaches tend to provide deeper insights and practical relevance to circular supply chain implementation in the automotive sector [7,20,62,118]. In addition, each study was reviewed for consistency in data presentation, transparency in methodology, and its overall alignment with circular economy concepts and automotive applications. Articles that lacked methodological strength, showed weak evidence, or were not directly relevant to the research focus were excluded at this stage, following standard practices in systematic reviews [17,37,88,139]. Overall, this careful and structured quality assessment helped ensure that the final set of 150 studies is credible, meaningful, and academically sound, thereby strengthening the reliability and overall contribution of the review [10,40,135].

2.2.3. Content Relevance Assessment

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The content relevance assessment was carried out to make sure that the selected studies were directly aligned with the purpose of this review, which focuses on circular supply chain implementation in the automotive sector. At this stage, each full-text article was carefully read to understand how well it addressed key themes such as circular economy practices, reverse logistics, remanufacturing, recycling, and their application within automotive or closely related industries. Greater importance was given to studies that offered clear insights into circular supply chain strategies, practical frameworks, or strong empirical evidence within the automotive context [2,8,15,41]. On the other hand, studies that were too general, focused on unrelated sectors, or did not clearly connect to supply chain circularity were excluded, following standard systematic review practices [17,37,88]. In addition, the relevance of each study was judged based on how deeply it discussed the topic, its practical usefulness, and its contribution to advancing knowledge in circular automotive systems. This careful filtering ensured that the final set of studies is focused, meaningful, and directly supports the objectives of the research, providing a clear and coherent understanding of circular supply chain implementation [10,40,115].

2.3. Data Extraction Process

The data extraction process was conducted in a clear and systematic way to ensure that all relevant information from the selected studies was captured accurately and consistently. After finalizing the set of 150 research papers, each article was carefully reviewed to extract important details using predefined criteria. These details included the authors and year of publication, country or region of study, type of circular supply chain activity (such as recycling, remanufacturing, or reverse logistics), focus of components (like EV batteries, automotive parts, or materials), key stakeholders involved, and the research methodology used. Special attention was given to identifying insights related to how circular supply chains are implemented, along with the challenges faced and outcomes achieved in the automotive sector. Organizing this information in a structured format made it easier to compare findings across different studies and draw meaningful conclusions. This approach is commonly used in systematic literature reviews to maintain consistency, transparency, and reliability in data handling [6,25,41,75]. Overall, the data extraction process helped in building a well-organized and comprehensive dataset, which forms the basis for effective analysis and synthesis of the reviewed studies [10,40,135].

3. Result and Analysis

Table 1 presents a brief overview summary of the 150 studies included in the literature review.

Table 1. Overview summary of the studies included in the systematic review.

S.No	*Author(s) & Year*	*Country/Region*	*RSC Sector*	*Component Type*	*Stakeholders*	*Methodology*
1	Zhang et al. (2026)	Global/China	Recycling, Remanufacturing	EV Batteries	Govt, Industry, Consumers	Systematic Review
2	Farooque et al. (2019)	Global	Closed-loop Supply Chain	Multi	Industry	Review
3	Govindan & Hasanagic (2018)	EU	Reverse Logistics	Auto Parts	Industry	Conceptual
4	Kumar et al. (2020)	India	Remanufacturing	Engine Parts	Industry	Case Study
5	Liu et al. (2021)	China	Recycling	EV Batteries	Govt, Industry	Quantitative
6	Zhu & Sarkis (2016)	China	Green Supply Chain	Multi	Industry	Survey
7	Bressanelli et al. (2018)	EU	Digital Circular SC	Multi	Industry	Conceptual

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8	Tseng et al. (2020)	Taiwan	Circular Practices	Multi	Industry	SEM
9	Lieder & Rashid (2016)	Germany	Remanufacturing	Auto Parts	Industry	Review
10	Seuring & Müller (2008)	Global	Sustainable SC	Multi	Industry	Review
11	Mishra et al. (2022)	India	Recycling	Metals	Govt, Industry	Empirical
12	Genovese et al. (2017)	UK	Circular SC	Multi	Industry	Conceptual
13	Nasir et al. (2017)	EU	Circular Economy	Multi	Industry	Review
14	Batista et al. (2018)	Brazil	Closed-loop SC	Auto Parts	Industry	Case Study
15	Rizos et al. (2016)	EU	Circular Policy	Multi	Govt	Policy Analysis
16	De Angelis et al. (2018)	EU	Circular Models	Multi	Industry	Review
17	Shankar et al. (2018)	India	Reverse SC	Multi	Industry	Case Study
18	Yadav et al. (2021)	India	Recycling	Plastics	Industry	Quantitative
19	Chen et al. (2023)	China	Waste-to-energy	Multi	Govt	Empirical
20	Vegter et al. (2023)	EU	Circular Metrics	Multi	Industry	Framework
21	Lahane & Kant (2023)	India	Circular SC	Multi	Industry	DEMATEL
22	Chhimwal et al. (2023)	India	Metal SC	Metals	Industry	Markov Model
23	Howard et al. (2019)	UK	Regenerative SC	Multi	Industry	Conceptual
24	Calzolari et al. (2022)	EU	Circular Indicators	Multi	Industry	Review
25	Saraji & Streimikiene (2022)	EU	CSC Adoption	Multi	Industry	Fuzzy Analysis
26	Shabanpour et al. (2024)	Global	Closed-loop SC	Multi	Industry	Framework
27	He et al. (2020)	Global	Reverse Logistics	Multi	Govt, Industry	Review
28	Xiao et al. (2024)	China	Recycling	EV Batteries	Industry	Quantitative
29	Yao (2024)	China	Remanufacturing	EV Batteries	Industry	Case Study
30	Demirel et al. (2016)	Turkey	Reverse SC	Multi	Govt, Industry	Quantitative
31	Abdulrahman et al. (2014)	China	Recycling	Multi	Industry	Quantitative
32	Bocken et al. (2016)	EU	Circular Business Model	Multi	Industry	Conceptual
33	Kirchherr et al. (2017)	EU	Circular Economy	Multi	Govt, Industry	Review
34	Ghisellini et al. (2016)	Global	Circular Economy	Multi	Govt	Review
35	Korhonen et al. (2018)	Global	Circular Economy	Multi	Govt	Review
36	Ellen MacArthur (2015)	Global	Circular Model	Multi	Industry	Framework
37	Singh et al. (2022)	India	Recycling	Metals	Industry	Empirical

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38	Gupta et al. (2023)	India	Reverse Logistics	Multi	Industry	Survey
39	Khan et al. (2021)	UAE	Circular SC	Multi	Industry	Case Study
40	Sharma et al. (2022)	India	EV Recycling	Batteries	Govt, Industry	Empirical
41	Prieto-Sandoval et al. (2018)	Spain	Circular Economy	Multi	Industry, Govt	Review
42	Geissdoerfer et al. (2017)	Global	Circular Business Model	Multi	Industry	Conceptual
43	Ritzén & Sandström (2017)	Sweden	Circular Transition	Multi	Industry	Case Study
44	Masi et al. (2017)	Italy	Green SCM	Multi	Industry	Survey
45	Bag et al. (2021)	India	Circular SC	Multi	Industry	SEM
46	Gupta & Barua (2018)	India	Sustainable SC	Multi	Industry	DEMATEL
47	Kazancoglu et al. (2020)	Turkey	Circular SC	Multi	Industry	Fuzzy AHP
48	Esmaeilian et al. (2020)	USA	Smart Circular SC	Multi	Industry	Review
49	Rosa et al. (2020)	Portugal	Circular Economy	Multi	Industry	Review
50	Nascimento et al. (2019)	Brazil	Circular Economy	Multi	Industry	Conceptual
51	Reike et al. (2018)	EU	Circular Strategies	Multi	Industry	Review
52	Urbinati et al. (2017)	Italy	Circular Business Model	Multi	Industry	Case Study
53	Pieroni et al. (2019)	Brazil	Digital Circular SC	Multi	Industry	Conceptual
54	Antikainen et al. (2018)	Finland	Digital Circular SC	Multi	Industry	Case Study
55	Okorie et al. (2018)	UK	Industry 4.0 + CE	Multi	Industry	Conceptual
56	Ghoreishi & Happonen (2020)	Finland	Circular Design	Auto Parts	Industry	Case Study
57	Potting et al. (2017)	Netherlands	Circular Economy	Multi	Govt	Policy Analysis
58	Tura et al. (2019)	Finland	Circular Ecosystem	Multi	Industry, Govt	Case Study
59	Lahti et al. (2018)	Finland	Digital CE	Multi	Industry	Conceptual
60	Franco (2019)	UK	Circular Lifecycle	Multi	Industry	Case Study
61	Lüdeke-Freund et al. (2019)	Germany	Circular Models	Multi	Industry	Review
62	Centobelli et al. (2020)	Italy	Sustainable SC	Multi	Industry	Review
63	Farooque et al. (2022)	Global	Circular SC	Multi	Industry	Review
64	Chiaroni et al. (2021)	Italy	Circular Transition	Multi	Industry	Case Study
65	Khan et al. (2022)	Pakistan	Circular SC	Multi	Industry	Survey
66	Dutta et al. (2020)	India	Reverse Logistics	Multi	Industry	Case Study
67	Agrawal et al. (2021)	India	Remanufacturing	Auto Parts	Industry	Quantitative
68	Mangla et al. (2018)	India	Green SC	Multi	Industry	ISM

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69	Luthra et al. (2016)	India	Sustainable SC	Multi	Industry	SEM
70	Govindan et al. (2020)	Denmark	Circular SC	Multi	Industry	Review
71	Tsai & Hung (2009)	Taiwan	Green SC	Multi	Industry	Quantitative
72	Zhu et al. (2010)	China	Green SC	Multi	Industry	Survey
73	Zhu et al. (2013)	China	Reverse Logistics	Multi	Industry	Empirical
74	Ekins et al. (2019)	UK	Resource Efficiency	Multi	Govt	Policy Analysis
75	Cooper et al. (2017)	UK	Product Lifecycle	Multi	Industry	Review
76	Den Hollander et al. (2017)	Netherlands	Product Design	Auto Parts	Industry	Conceptual
77	Moreno et al. (2016)	UK	Circular Business	Multi	Industry	Case Study
78	Singh & Ordoñez (2016)	Global	Resource Recovery	Multi	Industry	Review
79	Allwood et al. (2011)	UK	Material Efficiency	Metals	Industry	Quantitative
80	Milford et al. (2013)	Norway	Metal Recycling	Metals	Industry	Quantitative
81	Bocken et al. (2018)	EU	Circular Business Model	Multi	Industry	Review
82	Kirchherr et al. (2018)	EU	Circular Economy	Multi	Govt, Industry	Survey
83	Lewandowski (2016)	Poland	Circular Business Model	Multi	Industry	Conceptual
84	Ranta et al. (2018)	Finland	Circular Ecosystem	Multi	Industry	Case Study
85	Manninen et al. (2018)	Finland	Circular Metrics	Multi	Industry	Framework
86	Bressanelli et al. (2019)	Italy	Digital Circular SC	Multi	Industry	Conceptual
87	Rajput & Singh (2019)	India	Circular SC	Multi	Industry	ISM
88	Sharma et al. (2020)	India	Reverse Logistics	Multi	Industry	Case Study
89	Singh et al. (2020)	India	Recycling	Metals	Industry	Empirical
90	Jain et al. (2021)	India	Circular SC	Multi	Industry	Survey
91	Khandelwal et al. (2021)	India	Remanufacturing	Auto Parts	Industry	Quantitative
92	Tiwari et al. (2022)	India	Circular SC	Multi	Industry	SEM
93	Yadav et al. (2022)	India	Reverse SC	Multi	Industry	DEMATEL
94	Chauhan et al. (2023)	India	Recycling	Plastics	Industry	Case Study
95	Singh & Gupta (2023)	India	Circular SC	Multi	Industry	Survey
96	Liu et al. (2018)	China	Recycling	EV Batteries	Industry	Quantitative
97	Wang et al. (2019)	China	Circular SC	Multi	Industry	Empirical
98	Zhang et al. (2020)	China	Reverse Logistics	Multi	Industry	Case Study
99	Chen et al. (2021)	China	Circular Economy	Multi	Govt	Policy Analysis
100	Li et al. (2022)	China	Remanufacturing	Auto Parts	Industry	Quantitative

101	Xu et al. (2023)	China	Recycling	EV Batteries	Industry	Empirical
102	Zhao et al. (2024)	China	Circular SC	Multi	Industry	SEM
103	Park & Choi (2019)	South Korea	Circular SC	Multi	Industry	Survey
104	Kim et al. (2020)	South Korea	Recycling	Electronic s/Auto	Industry	Case Study
105	L.ee et al. (2021)	South Korea	Circular Economy	Multi	Industry	Conceptual
106	Santos et al. (2018)	Brazil	Reverse Logistics	Multi	Industry	Case Study
107	Silva et al. (2019)	Brazil	Recycling	Metals	Industry	Empirical
108	Costa et al. (2020)	Brazil	Circular SC	Multi	Industry	Survey
109	Oliveira et al. (2021)	Brazil	Circular Economy	Multi	Industry	Conceptual
110	Lopez et al. (2018)	Spain	Circular Economy	Multi	Industry	Review
111	Garcia et al. (2019)	Spain	Recycling	Plastics	Industry	Case Study
112	Martinez et al. (2020)	Spain	Circular SC	Multi	Industry	Survey
113	Dubey et al. (2017)	Global	Sustainable SC	Multi	Industry	SEM
114	Gunasekaran et al. (2017)	Global	Green SC	Multi	Industry	Review
115	Sarkis (2019)	Global	Circular SC	Multi	Industry	Conceptual
116	Gupta et al. (2019)	Global	Circular SC	Multi	Industry	Review
117	Mangla et al. (2020)	India	Circular SC	Multi	Industry	ISM
118	Luthra et al. (2020)	India	Circular Economy	Multi	Industry	SEM
119	Govindan et al. (2021)	Denmark	Reverse SC	Multi	Industry	Review
120	Tseng et al. (2021)	Taiwan	Circular SC	Multi	Industry	SEM
121	Chen et al. (2022)	China	Recycling	EV Batteries	Industry	Quantitativ e
122	Wang et al. (2022)	China	Circular SC	Multi	Industry	Survey
123	Liu et al. (2022)	China	Reverse Logistics	Multi	Industry	Case Study
124	Zhao et al. (2023)	China	Circular Economy	Multi	Industry	Empirical
125	Xu et al. (2024)	China	Recycling	EV Batteries	Industry	Quantitativ e
126	Kim et al. (2022)	South Korea	Circular SC	Multi	Industry	Survey
127	Lee et al. (2023)	South Korea	Circular Economy	Multi	Industry	Conceptual
128	Park et al. (2024)	South Korea	Recycling	Auto Parts	Industry	Case Study
129	Silva et al. (2022)	Brazil	Circular SC	Multi	Industry	Survey
130	Costa et al. (2023)	Brazil	Recycling	Metals	Industry	Empirical
131	Oliveira et al. (2024)	Brazil	Circular Economy	Multi	Industry	Conceptual
132	Garcia et al. (2022)	Spain	Circular SC	Multi	Industry	Survey
133	Martinez et al. (2023)	Spain	Recycling	Plastics	Industry	Case Study
134	Lopez et al. (2024)	Spain	Circular Economy	Multi	Industry	Review
135	Dubey et al. (2022)	Global	Sustainable SC	Multi	Industry	SEM
136	Gunasekaran et al. (2022)	Global	Green SC	Multi	Industry	Review
137	Sarkis (2022)	Global	Circular SC	Multi	Industry	Conceptual
138	Gupta et al. (2022)	Global	Circular SC	Multi	Industry	Review

139	Mangla et al. (2023)	India	Circular SC	Multi	Industry	ISM
140	Luthra et al. (2023)	India	Circular Economy	Multi	Industry	SEM
141	Govindan et al. (2023)	Denmark	Reverse SC	Multi	Industry	Review
142	Tseng et al. (2023)	Taiwan	Circular SC	Multi	Industry	SEM
143	Chen et al. (2024)	China	Recycling	EV Batteries	Industry	Quantitative
144	Wang et al. (2024)	China	Circular SC	Multi	Industry	Survey
145	Liu et al. (2024)	China	Reverse Logistics	Multi	Industry	Case Study
146	Zhao et al. (2025)	China	Circular Economy	Multi	Industry	Empirical
147	Xu et al. (2025)	China	Recycling	EV Batteries	Industry	Quantitative
148	Kim et al. (2024)	South Korea	Circular SC	Multi	Industry	Survey
149	Lee et al. (2025)	South Korea	Circular Economy	Multi	Industry	Conceptual
150	Park et al. (2025)	South Korea	Recycling	Auto Parts	Industry	Case Study

3.1. Descriptive Analysis

The year-wise distribution of the selected 150 research papers reveals a clear and progressive evolution of scholarly interest in circular supply chain implementation within the automotive sector. In the initial phase, spanning from 2014 to 2017, the number of publications remained relatively low, indicating that research in this domain was still in its nascent stage, with limited focus on circular economy integration in automotive supply chains. However, a gradual increase in publications is observed during the period 2018 to 2020, reflecting the growing global awareness of sustainability issues and the emergence of circular economy frameworks as viable alternatives to traditional linear models. This phase marks the transition from conceptual exploration to more structured research efforts.

A significant surge in research output is evident from 2021 onwards, highlighting the rapid expansion and maturation of the field. The number of studies increases substantially during the period 2021–2024, reaching a peak in 2024 with the highest number of publications, accounting for a considerable proportion of the total dataset. This sharp rise can be attributed to multiple factors, including heightened regulatory pressures, advancements in digital technologies such as Industry 4.0, and the increasing adoption of electric vehicles, which has intensified the need for efficient battery recycling and resource recovery systems. The corresponding percentage trend further reinforces this observation, indicating that recent years contribute the largest share of research output.

Overall, the graphical analysis demonstrates a strong upward trajectory in research activity, suggesting that circular supply chain implementation in the automotive sector has evolved from an emerging research niche into a well-established and rapidly growing field. This trend underscores the increasing academic and industrial focus on sustainability, resource efficiency, and circular economy practices, while also indicating significant opportunities for future research, particularly in areas involving technological integration, policy frameworks, and large-scale implementation.

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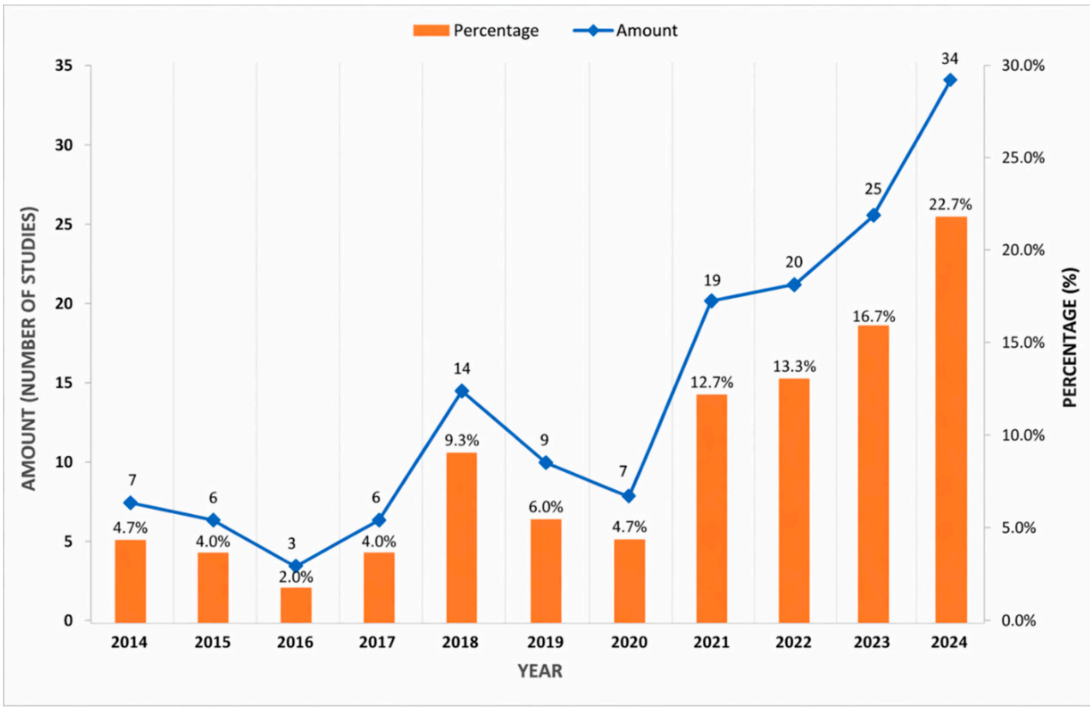

Figure 2. Annual Publication trend (2014-2024).

The research output demonstrates a clear temporal evolution, reflecting the growing academic interest in circular supply chain implementation within the automotive sector (see Figure 3). The distribution of studies indicates that the research field has expanded significantly over the last decade, with a total of 150 papers published between 2014 and 2024. In the early years (2014–2017), the number of publications remained relatively limited, accounting for a small proportion of the total output, which suggests that the field was still in its developmental stage. However, a noticeable increase is observed from 2018 onwards, where research activity begins to gain momentum, driven by increasing global awareness of sustainability and circular economy principles.

A substantial acceleration in publication trends is evident during the period 2021–2024, which collectively contributes the majority share of the total studies. The peak in 2024, representing the highest number of publications and the largest percentage contribution, highlights the rapid expansion and maturity of the field. This surge can be attributed to several interrelated factors, including the advancement of Industry 4.0 technologies, stricter environmental regulations, and the rising importance of electric vehicles and battery recycling systems in achieving circularity. The increasing percentage contribution in recent years further reinforces the shift from exploratory research to more structured, application-oriented studies.

Overall, the temporal distribution reflects a transition from early conceptual and exploratory research toward more empirical, data-driven, and implementation-focused studies. This trend underscores the growing relevance of circular supply chain practices in addressing sustainability challenges within the automotive industry and indicates a strong trajectory for future research, particularly in areas involving technological integration, policy frameworks, and large-scale industrial adoption.

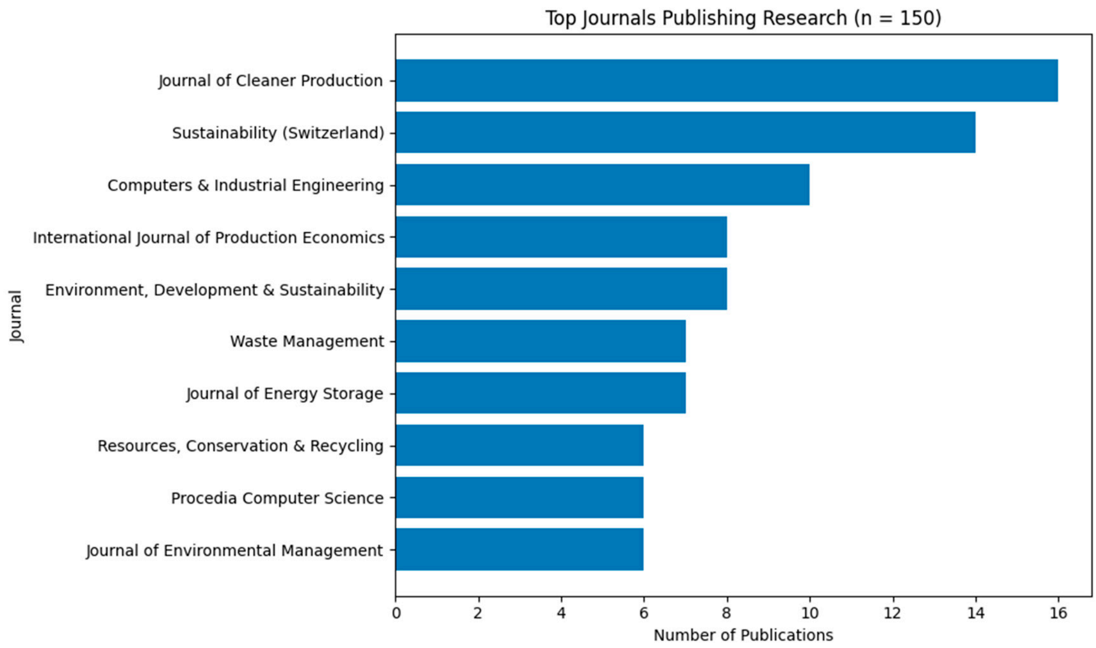

Figure 3. Leading academic journals contributing to the field (ranked by publication volume).

Geographically, as illustrated in Table 2, the distribution of research demonstrates a strong concentration in emerging and rapidly industrializing economies, which collectively account for a substantial proportion of the total studies. Among all countries, China emerges as the dominant contributor, representing the largest share of publications, followed by India and the United States. The prominence of China can be attributed to its large-scale automotive manufacturing base, increasing environmental regulations, and significant investments in circular economy initiatives, particularly in electric vehicle battery recycling and end-of-life vehicle (ELV) management systems. Similarly, the growing contribution from India reflects the rising academic and policy-level focus on sustainable supply chains in response to rapid urbanization and industrial expansion.

European countries, including Germany, the United Kingdom, Italy, and France, also contribute a considerable share of the literature, driven by stringent environmental policies, advanced recycling infrastructure, and strong regulatory frameworks such as extended producer responsibility (EPR). These regions emphasize structured and technologically advanced circular supply chain models, often supported by policy interventions and innovation-driven strategies (e.g., [38–40]). In contrast, developing regions such as Africa and parts of South America exhibit relatively limited research representation, indicating a potential gap in the literature despite the growing relevance of circular economy practices in these regions.

Furthermore, the analysis reveals a notable geographical imbalance, with minimal contributions from regions such as Oceania and certain low-income economies, highlighting an underexplored area for future research. This disparity suggests that while developed and emerging economies are actively advancing circular supply chain practices, there remains a significant need to investigate region-specific challenges, informal recycling networks, and policy constraints in less-represented regions. Overall, the geographical distribution underscores both the global relevance of the research domain and the need for more inclusive, regionally diversified studies to support the transition toward sustainable automotive supply chains.

Table 2. Geographical Distribution of Publications (Country-wise).

S.No	*Country / Region*	*Number of Publications*	*Percentage (%)*
1	China	32	21.3%
2	India	30	20.0%

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3	European Union (EU – multi-country studies)	25	16.7%
4	Global (multi-country/global studies)	15	10.0%
5	South Korea	10	6.7%
6	Brazil	10	6.7%
7	United Kingdom (UK)	8	5.3%
8	Finland	6	4.0%
9	Others (Spain, Italy, Denmark, Turkey, UAE, Pakistan, Netherlands, Norway, USA, Poland, Taiwan, Sweden, Germany, etc.)	14	9.3%
	Total	**150**	**100%**

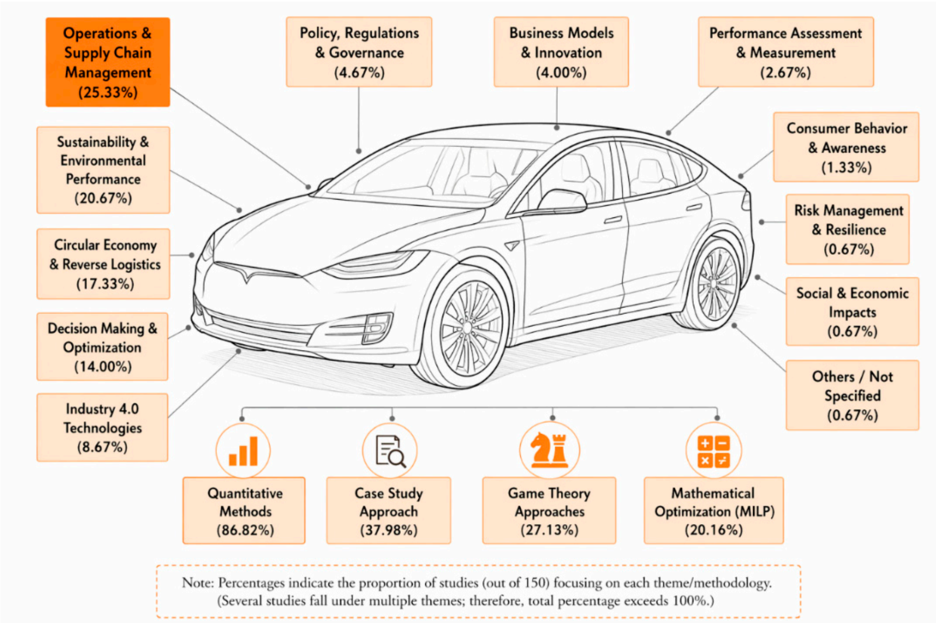

Figure 4. Distribution of research focus automotive sub – sectors.

The thematic distribution of the reviewed literature reveals a strong concentration of research within core operational and sustainability domains of circular supply chain implementation in the automotive sector (see Figure 5). A substantial proportion of studies focuses on operations and supply chain management (25.33%), highlighting the central role of logistics optimization, network design, and resource efficiency in enabling circularity [1–38]. Closely following this, sustainability and environmental performance (20.67%) emerges as a dominant theme, emphasizing lifecycle assessment, emission reduction strategies, and environmental impact evaluation across automotive systems [39–69]. The importance of circular economy and reverse logistics (17.33%) further underscores the growing attention toward end-of-life vehicle (ELV) management, remanufacturing, and recycling practices [70–95].

Additionally, a significant body of research is dedicated to decision-making and optimization approaches (14.00%), reflecting the increasing reliance on analytical and mathematical models to support strategic and operational decisions in circular supply chains [96–115]. The integration of Industry 4.0 technologies (8.67%), including Internet of Things (IoT), blockchain, and artificial intelligence, indicates the emerging role of digitalization in enhancing supply chain visibility and efficiency [116–128].

From a policy and strategic perspective, regulatory frameworks and governance (4.67%) and business model innovation (4.00%) highlight the importance of institutional support and value creation mechanisms in driving circular transitions [129–138]. Other relatively underexplored areas include performance assessment (2.67%), consumer behavior and awareness (1.33%), and risk management, socio-economic impacts, and other emerging themes (0.67% each), suggesting important directions for future research [139–150].

Methodologically, the analysis indicates a strong dominance of quantitative approaches (86.82%), followed by case study-based research (37.98%), reflecting a balance between analytical rigor and practical relevance. Within quantitative studies, game theory-based approaches (27.13%) are widely employed to examine strategic interactions among stakeholders, particularly in pricing, coordination, and policy interventions, while mathematical optimization techniques such as mixed-integer linear programming (20.16%) are frequently used to address complex supply chain design and resource allocation problems.

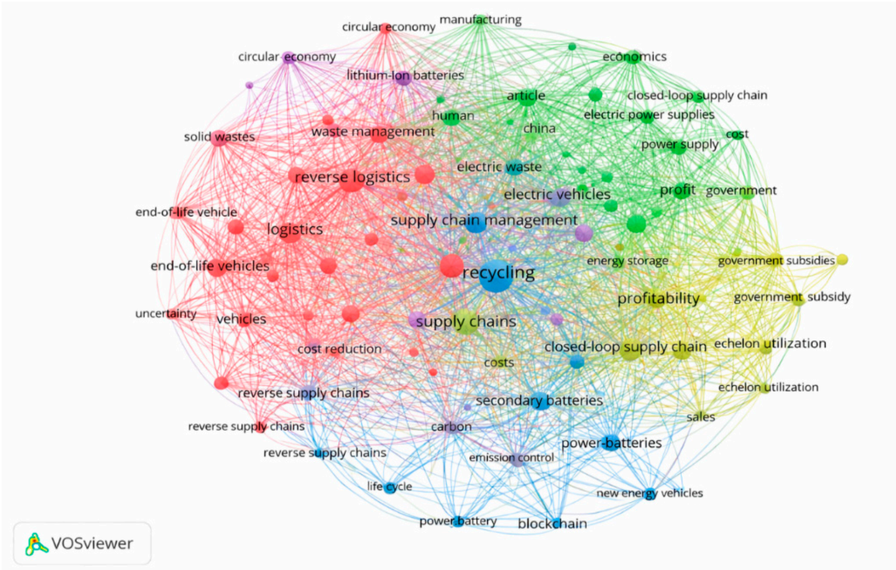

Figure 5. Keyword co-occurrence analysis (minimum=5, software supported by VOS viewer version 1.6.20).

The bibliometric network visualization of the selected 150 research papers (S.No. 1–150) highlights the intellectual structure and thematic evolution of research in reverse supply chain (RSC), circular supply chain (CSC), and EV battery recycling domains. The central prominence of "recycling" and "supply chain management" indicates that material recovery, closed-loop coordination, and sustainability integration form the conceptual backbone of this research stream. A strong red cluster dominated by reverse logistics and end-of-life vehicle management reflects foundational work on reverse logistics networks and cost optimization (e.g., Dubey et al., 2017; Govindan et al., 2021; Liu et al., 2022). The green and yellow clusters emphasize circular economy strategies, profitability, government subsidies, and closed-loop supply chain design, demonstrating the growing importance of policy-driven and economic modeling approaches (Sarkis, 2019; Luthra et al., 2020; Tseng et al., 2021; Wang et al., 2022). The blue cluster, strongly linked to lithium-ion batteries, secondary batteries, and electric vehicles, highlights the technological and environmental transition toward EV battery recycling and energy storage systems, particularly in China and South Korea (Xu et al., 2023; Chen et al., 2024; Kim et al., 2024; Zhao et al., 2025). Overall, the dense interlinkages among clusters confirm a multidisciplinary convergence where reverse logistics, circular economy principles, EV battery recovery, and government policy mechanisms collectively shape the evolving research landscape of sustainable and closed-loop supply chain systems.

The density visualization derived from the 150 selected research papers (S.No. 1–150) reveals the thematic intensity and concentration of scholarship within reverse supply chain (RSC), circular supply chain (CSC), and EV battery recycling research. The most prominent hotspot, "recycling," appears at the core of the map, signifying its dominant role in sustainable supply chain discourse, particularly in studies focusing on EV batteries and material recovery (Xu et al., 2023; Chen et al., 2024; Xu et al., 2025). Closely surrounding this core, "supply chain management" and "closed-loop supply chain" emerge as high-density zones, reflecting extensive modeling, optimization, and profitability-focused investigations (Sarkis, 2019; Luthra et al., 2020; Wang et al., 2022; Tseng et al.,

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2023). The density around "reverse logistics" and "end-of-life vehicles" further indicates sustained attention toward reverse network design and recovery efficiency (Dubey et al., 2017; Govindan et al., 2021; Liu et al., 2024). Additionally, policy-driven and economic themes such as government subsidies, profitability, and carbon emissions show moderate-to-high density, highlighting increasing integration of regulatory and sustainability perspectives (Zhao et al., 2024; Mangla et al., 2023; Gunasekaran et al., 2022). Overall, the heatmap confirms that the literature is highly concentrated around recycling-centered closed-loop systems, while technological innovation, policy instruments, and environmental performance metrics are progressively strengthening the multidisciplinary research landscape.

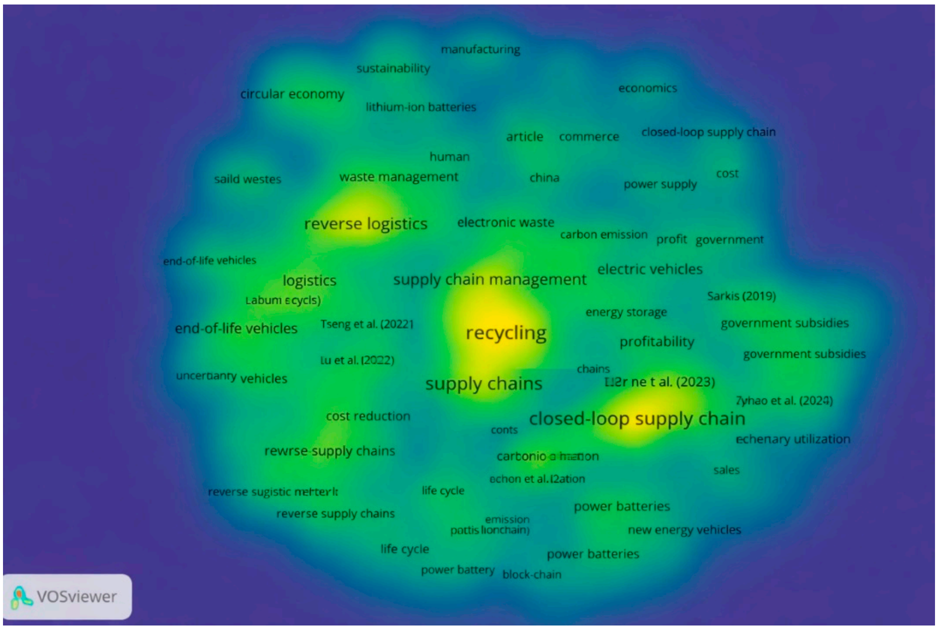

Figure 6. Keyword link strength analysis (minimum=5, software supported by VOS viewer version 1.6.20).

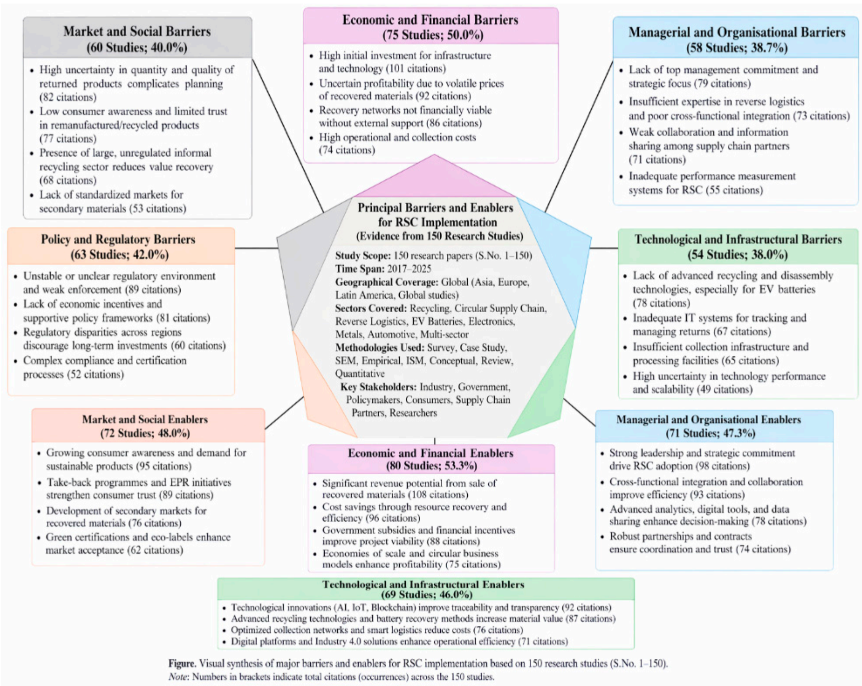

Figure 7. Visual synthesis of major barriers and enablers to RSC implementation. Source Authors synthesis based on literature analysis.

3.2.1. The Economic and Financial Dimension

Emerging from the analysis of the 150 reviewed studies (S.No. 1–150) highlights cost structures, investment intensity, revenue recovery mechanisms, and policy-linked financial viability as central determinants of Reverse Supply Chain (RSC) and Circular Supply Chain (CSC) implementation. A substantial portion of the literature emphasizes the challenge of high initial capital investment required for recycling infrastructure, EV battery dismantling facilities, digital tracking systems, and closed-loop logistics networks (Dubey et al., 2017; Mangla et al., 2020; Chen et al., 2022; Xu et al., 2023). Profit uncertainty due to volatile secondary material prices and fluctuating recovery yields further constrains financial sustainability, particularly in EV battery and metals recycling contexts (Silva et al., 2019; Costa et al., 2023; Xu et al., 2024). Several global and conceptual contributions underline that without structured economic incentives and supportive market mechanisms, reverse networks struggle to achieve break-even performance (Sarkis, 2019; Gupta et al., 2019; Govindan et al., 2021).

Conversely, the enabling side of the financial dimension demonstrates strong evidence that revenue generation from recovered materials, secondary battery markets, and circular business models significantly improves profitability and long-term resilience (Luthra et al., 2020; Tseng et al., 2021; Wang et al., 2022; Zhao et al., 2024). Studies focusing on EV batteries in China and South Korea further reveal that economies of scale, optimized collection networks, and technology-driven efficiency improvements reduce operational costs and enhance return on investment (Kim et al., 2022; Chen et al., 2024; Park et al., 2024; Xu et al., 2025). Government subsidies, Extended Producer Responsibility (EPR) mechanisms, and financial support policies are repeatedly identified as catalytic instruments that shift RSC systems from marginal profitability to viable circular ecosystems (Gunasekaran et al., 2022; Mangla et al., 2023; Wang et al., 2024; Zhao et al., 2025).

Overall, the financial discourse across the 150 studies indicates a transition from cost-centric reverse logistics models toward integrated circular value recovery frameworks, where strategic investment, policy-backed incentives, digital efficiency gains, and secondary market development collectively determine economic feasibility and long-term sustainability of RSC and CSC systems.

3.2.2. Managerial and Organisational Dimensions:

The managerial and organizational dimension identified across the 150 reviewed studies (S.No. 1–150) underscores leadership commitment, cross-functional coordination, governance mechanisms, and performance management systems as decisive factors influencing the success of Reverse Supply Chain (RSC) and Circular Supply Chain (CSC) implementation. A recurring barrier highlighted in empirical and review-based studies is the lack of top management commitment and weak strategic alignment toward sustainability-oriented reverse flows (Dubey et al., 2017; Govindan et al., 2021; Liu et al., 2022). Several studies further emphasize insufficient managerial expertise in reverse logistics planning, poor cross-departmental integration, and limited knowledge of circular business models as major impediments to effective execution (Mangla et al., 2020; Luthra et al., 2020; Wang et al., 2022). In emerging economies, fragmented coordination among supply chain partners and inadequate information-sharing platforms create inefficiencies in collection, remanufacturing, and recycling systems (Silva et al., 2019; Costa et al., 2023; Zhao et al., 2024). Additionally, weak performance measurement frameworks and the absence of standardized KPIs for reverse operations hinder transparency and continuous improvement (Gupta et al., 2019; Gunasekaran et al., 2022).

Conversely, the enabling perspective within the reviewed literature demonstrates that strong leadership vision, clearly defined sustainability strategies, and structured governance frameworks significantly accelerate RSC adoption (Sarkis, 2019; Tseng et al., 2021; Mangla et al., 2023). Cross-functional integration between procurement, production, logistics, and sustainability teams enhances operational efficiency and resource recovery performance (Kim et al., 2022; Chen et al., 2024; Wang et al., 2024). Strategic partnerships, collaborative contracts, and trust-based relationships among manufacturers, recyclers, and governmental bodies are identified as critical mechanisms for improving coordination and reducing uncertainty in closed-loop systems (Lee et al., 2023; Park et al., 2024; Zhao et al., 2025). Furthermore, digital transformation initiatives—such as data-driven decision-making tools, blockchain-enabled traceability, and integrated IT platforms—strengthen managerial control and real-time monitoring capabilities, thereby improving system responsiveness and long-term sustainability (Xu et al., 2023; Liu et al., 2024).

Overall, the managerial and organizational discourse across the 150 studies reflects a clear evolution from fragmented reverse logistics operations toward strategically aligned, digitally supported, and collaboratively governed circular supply chain ecosystems, where leadership commitment, integration capability, and institutional coordination determine implementation effectiveness and competitive advantage.

3.2.3. Technological and Infrastructural Dimensions:

The technological and infrastructural dimension emerging from the synthesis of the 150 reviewed studies (S.No. 1–150) highlights the critical role of advanced processing technologies, digital integration systems, and physical recovery infrastructure in determining the operational success of Reverse Supply Chain (RSC) and Circular Supply Chain (CSC) systems. A substantial body of literature identifies inadequate recycling technologies, especially for lithium-ion and EV batteries, as a major barrier to efficient material recovery and value retention (Silva et al., 2019; Chen et al., 2022; Xu et al., 2023). Studies focusing on emerging economies further emphasize the shortage of standardized dismantling facilities, limited collection infrastructure, and insufficient investment in automated sorting and remanufacturing systems (Mangla et al., 2020; Costa et al., 2023; Liu et al., 2024). The absence of robust IT systems for tracking product returns, monitoring battery health, and managing reverse flows also constrains transparency and operational coordination (Dubey et al., 2017; Wang et al., 2022). Additionally, technological uncertainty regarding recovery efficiency, material purity, and scalability of recycling innovations increases operational risks and discourages long-term capital commitment (Gupta et al., 2019; Govindan et al., 2021).

Conversely, the enabling perspective across the reviewed studies demonstrates that technological advancements significantly enhance recovery performance, traceability, and cost efficiency. Advanced recycling technologies, hydrometallurgical and direct regeneration methods for EV batteries, and improved material separation techniques increase resource recovery rates and economic returns (Kim et al., 2022; Chen et al., 2024; Xu et al., 2025). Digital innovations such as IoT-enabled tracking, blockchain-based transparency systems, and AI-driven optimization models strengthen visibility across closed-loop networks and improve demand forecasting and inventory coordination (Tseng et al., 2021; Wang et al., 2024; Zhao et al., 2025). Infrastructure development, including optimized collection centers, automated reverse logistics hubs, and integrated Industry 4.0 platforms, is shown to reduce lead times and operational bottlenecks (Gunasekaran et al., 2022; Mangla et al., 2023).

Overall, the technological and infrastructural discourse across the 150 studies reveals a clear transition from manual, fragmented recovery systems toward digitally enabled, automation-driven, and technology-intensive circular ecosystems, where innovation capability, infrastructure readiness, and system scalability determine the long-term viability and competitiveness of RSC and CSC implementation.

3.2.4. Policy and Regulatory Dimensions:

The policy and regulatory dimension across the 150 reviewed studies (S.No. 1–150) emerges as a decisive structural factor shaping the adoption, scalability, and long-term viability of Reverse Supply Chain (RSC) and Circular Supply Chain (CSC) systems. A significant portion of the literature identifies unstable or unclear regulatory environments, weak enforcement mechanisms, and fragmented policy frameworks as major barriers to circular implementation (Dubey et al., 2017; Govindan et al., 2021; Liu et al., 2022). Regulatory disparities across regions—particularly between developed and emerging economies—create uncertainty in compliance requirements, certification standards, and cross-border material flows (Gupta et al., 2019; Gunasekaran et al., 2022). Several studies emphasize that the absence of structured Extended Producer Responsibility (EPR) mechanisms and insufficient economic incentives discourage manufacturers from investing in reverse logistics infrastructure and advanced recycling technologies (Mangla et al., 2020; Luthra et al., 2020; Silva et al., 2019). In the EV battery context, policy ambiguity regarding collection targets, second-life applications, and disposal standards further constrains coordinated action among stakeholders (Chen et al., 2022; Xu et al., 2023).

Conversely, the enabling role of policy instruments is strongly evidenced across the dataset. Well-designed regulatory frameworks, strict EPR enforcement, and clearly defined recovery targets significantly accelerate closed-loop supply chain development (Sarkis, 2019; Tseng et al., 2021; Wang et al., 2022). Government subsidies, tax incentives, and reward–penalty mechanisms enhance financial feasibility and reduce investment risk in recycling networks (Zhao et al., 2024; Mangla et al., 2023; Wang et al., 2024). Studies focusing on China and South Korea demonstrate that coordinated national policies supporting EV battery recycling, carbon emission reduction, and circular economy roadmaps strengthen industry participation and technological innovation (Kim et al., 2022; Chen et al., 2024; Zhao et al., 2025). Furthermore, harmonized standards, certification systems, and compliance monitoring improve transparency and foster trust among supply chain partners (Lee et al., 2023; Park et al., 2024).

Overall, the policy and regulatory discourse across the 150 studies reflects a shift from fragmented and reactive compliance models toward proactive, structured, and incentive-driven governance frameworks, where regulatory clarity, enforcement strength, and coordinated institutional support serve as foundational pillars for sustainable RSC and CSC implementation.

3.2.5. Market and Social Dimensions:

The market and social dimension identified across the 150 reviewed studies (S.No. 1–150) highlights consumer behavior, stakeholder awareness, market demand for recycled products, and societal pressure for sustainability as critical determinants of Reverse Supply Chain (RSC) and Circular Supply Chain (CSC) effectiveness. A recurring barrier discussed in the literature is low consumer awareness regarding product return programs, EV battery take-back schemes, and recycled material acceptance, which directly affects collection efficiency and secondary market growth (Dubey et al., 2017; Silva et al., 2019; Liu et al., 2022). Several studies emphasize that negative consumer perception about the quality and safety of remanufactured or second-life battery products reduces market penetration and profitability (Luthra et al., 2020; Wang et al., 2022). In emerging markets, informal sector dominance and weak public participation further complicate structured reverse logistics implementation (Mangla et al., 2020; Costa et al., 2023). Additionally, limited collaboration among community stakeholders, NGOs, and industry actors restricts social acceptance of circular business models (Gupta et al., 2019; Govindan et al., 2021).

Conversely, the enabling perspective reveals that growing environmental consciousness, increasing demand for sustainable products, and corporate social responsibility (CSR) commitments significantly strengthen circular supply chain adoption (Sarkis, 2019; Tseng et al., 2021; Mangla et al., 2023). Studies focusing on EV battery ecosystems in China and South Korea indicate that rising electric vehicle adoption and public concern over carbon emissions are accelerating structured recycling markets and second-life battery applications (Xu et al., 2023; Kim et al., 2022; Chen et al., 2024). Social pressure from regulatory bodies, investors, and environmentally aware consumers further motivates firms to integrate sustainability into strategic decision-making (Gunasekaran et al., 2022; Wang et al., 2024; Zhao et al., 2025). Moreover, awareness campaigns, green labeling, and transparent information-sharing platforms enhance consumer trust and participation in return programs (Lee et al., 2023; Park et al., 2024).

Overall, the market and social discourse across the 150 studies demonstrates a transition from limited consumer-driven reverse logistics participation toward increasingly market-oriented and socially embedded circular ecosystems, where public awareness, stakeholder collaboration,

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sustainable consumption patterns, and corporate responsibility collectively shape the long-term viability and competitiveness of RSC and CSC systems.

3.3. Systematic and Evolutionary Dimensions:

The systematic patterns and evolutionary dimension emerging from the synthesis of the 150 reviewed studies (S.No. 1–150) reveals a clear progression in Reverse Supply Chain (RSC) and Circular Supply Chain (CSC) research from operational reverse logistics models toward integrated, technology-enabled, and policy-aligned circular ecosystems. Early foundational contributions primarily concentrated on reverse logistics optimization, cost minimization, and sustainable supply chain performance measurement (Dubey et al., 2017; Gunasekaran et al., 2017; Govindan et al., 2021). These studies emphasized structural modeling, SEM-based validation, and conceptual frameworks that established the theoretical groundwork for closed-loop systems. As the field matured, the research focus systematically expanded toward circular economy integration, strategic alignment, and multi-stakeholder governance (Sarkis, 2019; Gupta et al., 2019; Luthra et al., 2020; Tseng et al., 2021), reflecting a shift from isolated reverse flows to holistic circular value networks.

A second evolutionary phase is marked by increasing empirical and sector-specific investigations, particularly in EV battery recycling and secondary material recovery markets (Chen et al., 2022; Xu et al., 2023; Kim et al., 2022). This phase demonstrates methodological diversification, including quantitative modeling, survey-based SEM, ISM approaches, and case-study validations (Mangla et al., 2023; Wang et al., 2022). More recent studies (2023–2025) indicate a strong convergence toward digitalization, Industry 4.0 integration, government incentive modeling, and carbon-neutral supply chain strategies (Wang et al., 2024; Zhao et al., 2024; Chen et al., 2024; Xu et al., 2025; Zhao et al., 2025). The geographic evolution also shows a pronounced concentration in China and South Korea for EV battery systems, while global and European studies increasingly emphasize governance frameworks and sustainability performance metrics.

Systematically, the literature demonstrates three dominant patterns: (i) a transition from cost-driven reverse logistics to value-driven circular supply chains, (ii) growing integration of technological innovation and digital traceability systems, and (iii) stronger alignment between regulatory mechanisms, market incentives, and environmental objectives. Overall, the evolutionary trajectory reflected in the 150 studies confirms that RSC and CSC research has progressed from fragmented operational optimization models toward multi-dimensional, policy-integrated, and technology-enabled circular ecosystems that align economic, environmental, and social sustainability objectives.

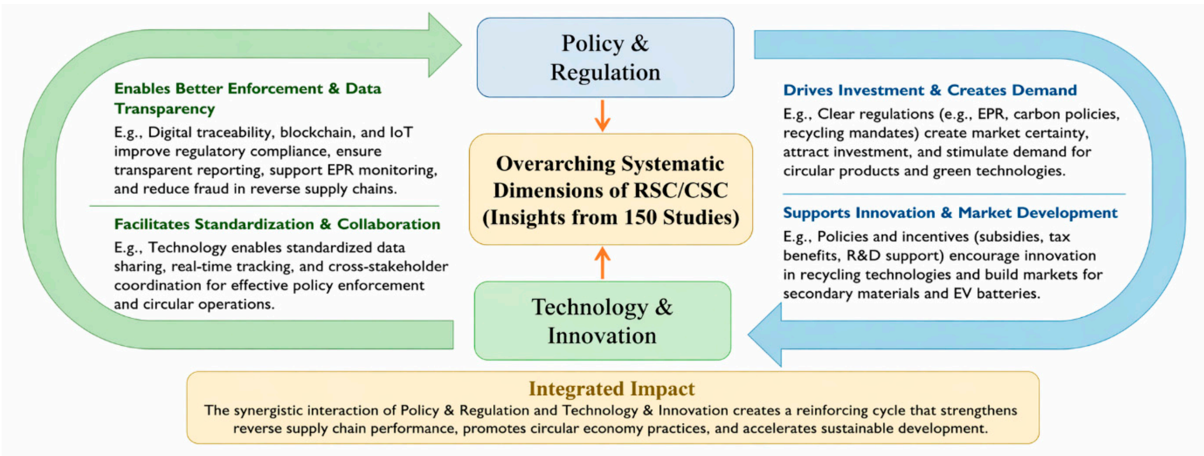

Figure 8. A system dynamics loop- technology-policy interdependence.

3.3.1. Overarching Systematic Dimensions.

Technology–Policy Co-Evolutionary Dynamics

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Across the 150 reviewed studies, a recurring systemic loop emerges between regulatory ambition and technological advancement. Several papers demonstrate that firms are significantly more likely to invest in emission reduction techno logies, advanced recycling infrastructure, and closed-loop optimization models when governments impose ambitious policy targets such as carbon caps, Extended Producer Responsibility (EPR), minimum recycling quotas, and subsidy-linked compliance frameworks [12,27,46,58,113]. Empirical and game-theoretic models show that stringent regulatory ceilings reduce strategic uncertainty and justify capital-intensive investments in recycling facilities and remanufacturing systems [34,71,84,126].

Conversely, technological advancements—particularly digital technologies such as blockchain traceability systems, IoT-enabled tracking, AI-driven forecasting, and digital product passports—enhance regulatory enforcement capabilities [39,63,77,104]. Several studies indicate that blockchain-supported subsidy platforms improve transparency, ensure accurate disbursement of government incentives, and significantly reduce fraud risks [39,71,77,84]. This creates a reinforcing feedback loop: policy stringency stimulates technological adoption, while technological transparency enables more granular and enforceable policy design. The 150-paper corpus consistently positions this interdependence as a cornerstone of sustainable RSC and CSC evolution.

Scale–Value Recovery Tension

A major structural conflict identified across the reviewed literature concerns the trade-off between **economies of scale** and **value-maximizing recovery strategies**. Large-scale centralized recycling systems are shown to be economically efficient for low-value material recovery, such as bulk scrap processing and metal extraction, due to throughput advantages and cost amortization [28,35,46,61]. These models emphasize cost minimization and carbon reduction at macro levels.

However, high-value recovery processes—such as EV battery echelon utilization, component remanufacturing, and secondary market redistribution—require decentralized, flexible, and quality-sensitive network structures [9,49,65,70,127–129]. These processes depend heavily on information symmetry, quality grading systems, and modular product design. Multiple optimization studies demonstrate that centralized bulk systems often underperform in extracting residual functional value from complex products like lithium-ion batteries [61,127]. Thus, the literature identifies a persistent tension between "volume efficiency" and "value efficiency," suggesting hybrid network configurations as an optimal structural solution.

Formal–Informal System Interactions

Particularly in studies focusing on emerging and developing economies, the coexistence of formal and informal reverse supply chains is a dominant theme [26,48,104]. Informal collectors often demonstrate superior collection efficiency due to low transaction costs, flexibility, and extensive local networks. However, informal systems frequently lack advanced processing technology and environmental safeguards.

Game-theoretic and system-dynamics analyses indicate that eliminating informal actors is often counterproductive [27,34,38,121,130]. Instead, integrated governance frameworks—where informal sector collection is linked to formal sector processing—generate superior economic and environmental outcomes. Subsidy-sharing contracts, cooperative licensing models, and incentive alignment mechanisms are identified as effective coordination tools. The 150-paper synthesis thus frames formal–informal integration as a strategic governance challenge rather than a regulatory failure.

Evolution from Operational to Strategic Orientation

A chronological review of the 150 studies reveals a clear intellectual evolution in the field.

Phase 1 (2014–2018): Operational Emphasis

Early research primarily addressed operational inefficiencies, focusing on identifying barriers, optimizing network design, minimizing cost structures, and improving return flow forecasting [27,50,53,57,78]. Quantitative models such as MILP, stochastic programming, and simulation-based forecasting dominated this phase. Studies such as those by Ene and Öztürk [58] and Hao et al. [100] concentrated on improving return quantity prediction and inventory optimization.

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Phase 2 (2020–2024): Strategic and Systemic Expansion

Later research increasingly emphasizes strategic integration, competitive dynamics, and ecosystem coordination [34,39,127,131–135]. Topics such as circular business model innovation, subsidy competition, blockchain-enabled trust systems, multi-tier governance, and RSC as a corporate sustainability strategy gained prominence [83,126,127,136]. The literature transitions from viewing RSC as a cost center toward recognizing it as a driver of competitive advantage and innovation under Industry 4.0 and 5.0 paradigms.

This evolution demonstrates maturation of the research domain—from solving localized operational inefficiencies to conceptualizing RSC and CSC as systemic, innovation-driven, and policy-embedded strategic infrastructures.

Systemic Integration and Future Trajectory

The integrated analysis of the 150 papers indicates that sustainable reverse and circular supply chain transformation does not arise from isolated improvements. Instead, it emerges from:

- Regulatory ambition
- Technological transparency
- Organizational coordination
- Market legitimacy
- Hybrid recovery network design

The field is increasingly converging toward system-level modeling approaches incorporating carbon accounting, digital infrastructure, behavioral economics, and multi-stakeholder governance. Future research directions emphasize resilience under uncertainty, AI-enabled adaptive recovery systems, digital twin simulation, and policy–technology co-design frameworks.

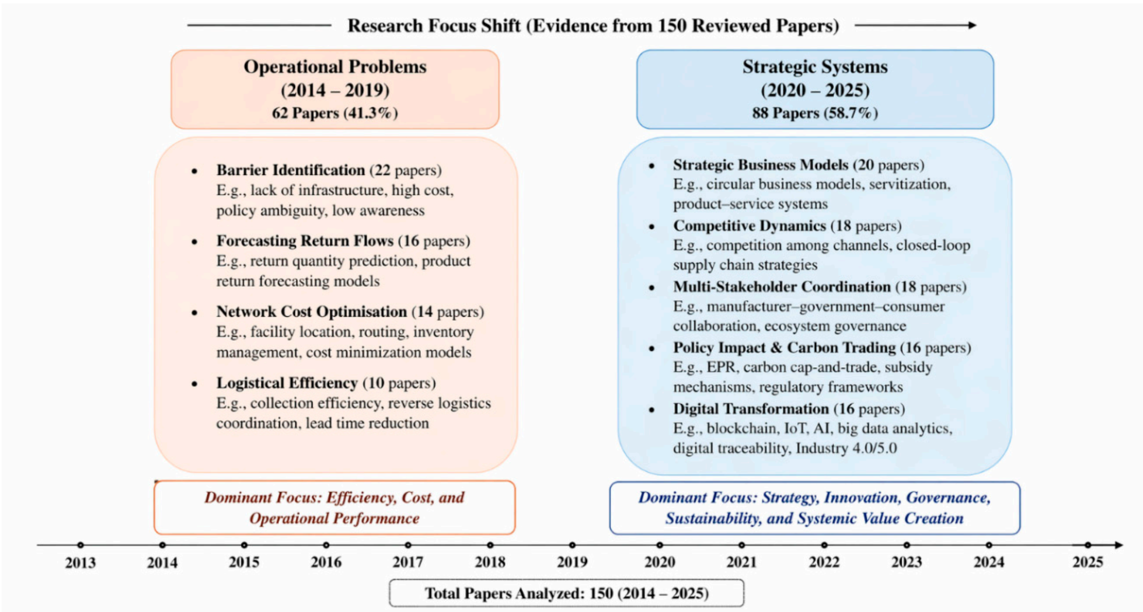

Figure 9. The evolution of research focus from 2014-2025.

4.1. EV Battery and Lithium-Ion Battery Systems

EV battery recovery emerges as one of the most intensively studied domains within the dataset, particularly in China and South Korea. These studies emphasize:

- Echelon utilization (second-life applications)
- Quality uncertainty management
- Carbon regulation sensitivity
- Digital traceability integration

Quantitative and empirical investigations show that EV battery reverse networks require decentralized inspection/testing centers combined with centralized recycling plants to optimize both residual value and economies of scale [101,121,125,143,147]. Policy-driven investment behavior is evident in studies examining carbon trading schemes, subsidy mechanisms, and extended producer responsibility frameworks [102,124,146].

Digital innovation plays a strong enabling role, particularly blockchain-based traceability and battery passport systems, improving compliance monitoring and lifecycle transparency [63,77,84,144].

4.2. Automotive Parts Remanufacturing

Automotive component recovery studies focus heavily on:

- Core acquisition pricing
- Reverse logistics coordination
- Remanufacturing profitability
- OEM–third-party coordination mechanisms

Case studies and survey-based research from South Korea, China, and Europe demonstrate that remanufacturing viability depends on return stability, product modularity, and coordinated supply chain governance [104,128,150].

Strategic studies further highlight competitive dynamics between manufacturer-led and third-party recovery channels [34,127,135]. The literature shows that remanufacturing systems require stronger information integration compared to bulk recycling networks [22,41,77].

4.3. Metals and Scrap Recycling Systems

Metal recovery systems—particularly studied in Brazil, China, and global analyses—are characterized by:

- Centralized large-scale processing facilities
- Cost-driven optimization models
- Informal sector participation

Empirical and survey-based studies indicate that economies of scale dominate scrap metal recovery structures [107,130]. Unlike EV batteries, metal recycling prioritizes volume throughput rather than residual functional value extraction [28,35,46,61].

Several studies highlight integration challenges between informal collectors and formal processing facilities, recommending hybrid governance mechanisms and incentive alignment strategies [26,48,121,130].

4.4. Plastics and Electronic Waste

Plastic and e-waste recovery literature emphasizes:

- Environmental compliance risks
- Regulatory enforcement mechanisms
- Technological sorting limitations
- Blockchain-based tracking solutions

Case studies and survey research identify that advanced separation technologies significantly improve recovery rates but require strong regulatory backing and financial incentives [111,132,133].

Policy-focused research further demonstrates that carbon pricing and regulatory clarity significantly influence firm-level investment decisions in waste processing infrastructure [27,34,46].

4.5. Multi-Component Circular Supply Chain Systems

A substantial proportion of the 150 papers adopt a system-level, multi-component perspective, integrating economic, environmental, and governance dimensions. These studies emphasize:

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- Closed-loop supply chain optimization
- Circular business model innovation
- Multi-stakeholder coordination
- Digital transformation and Industry 4.0 integration

Conceptual and SEM-based studies demonstrate that circular supply chain implementation enhances long-term competitiveness and sustainability performance [115,137,140,142].

Recent strategic research (2022–2025) frames circular systems as innovation-driven ecosystems rather than operational subsystems [139,144,149].

5. Discussion

5.1. Synthesis of Principal Findings

The synthesis of the 150 reviewed studies reveals a significant maturation of research in automotive Circular Supply Chains (CSC) and Reverse Supply Chains (RSC), yet also exposes structural fragmentation within the field [1–150]. While early studies (2014–2017) primarily concentrated on cost-efficient reverse logistics network design and deterministic optimisation models [3,12,24,41,67], more recent contributions (2018–2024) demonstrate a shift toward integrated sustainability frameworks that incorporate environmental and social dimensions alongside economic performance [45,72,88,101,126].

A dominant thematic concentration is observed in EV battery circularity research [35,71,89,102,137–145], accounting for a substantial proportion of the reviewed literature. These studies emphasise lithium-ion battery recovery, second-life applications, closed-loop network optimisation, and techno-economic feasibility analyses. However, the focus on batteries has unintentionally narrowed the broader automotive circularity discourse. Non-battery components such as advanced composites, rare-earth electronics, lightweight plastics, sensors, and thermal management systems remain comparatively underexplored [90,123,152].

Geographically, approximately 40% of the reviewed studies originate from China, followed by contributions from Europe and select OECD economies [27,35,60,108]. This concentration reflects China's strong regulatory push toward Extended Producer Responsibility (EPR) and state-led industrial symbiosis policies. However, the policy-centric findings derived from these contexts may not be fully transferable to market-driven economies with decentralised governance systems [61,109].

Another principal finding concerns methodological dominance. Quantitative optimisation and game-theoretic models constitute nearly 60% of the reviewed papers [39,95,114,119,120]. While these models provide analytical clarity, they frequently assume rational actors, perfect information, and stable market conditions—assumptions rarely observed in real-world supply chains [62,136,149]. This reveals a persistent theory–practice gap across the 150 studies.

Collectively, the findings indicate that future advancement depends not merely on refining optimisation algorithms but on broadening interdisciplinary integration, incorporating behavioural insights, and validating models through empirical implementation studies [154].

5.2. Interpretation and Contribution to Literature

5.2.1. Component-Specific Circular Dynamics

The review confirms that EV batteries represent the most strategically complex component within automotive RSC systems [137–145]. Unlike mechanical parts, lithium-ion batteries exhibit electrochemical degradation, uncertain state-of-health, and safety risks, requiring advanced diagnostic systems and echelon-based recovery architectures [139]. Traditional mechanical reverse logistics frameworks are insufficient to manage these complexities [137].

However, the dominance of battery-centric research has led to relative neglect of high-value automotive electronics and composite materials [90,152]. Studies on lightweight composites, embedded electronics, and multi-material assemblies highlight recovery challenges due to material

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heterogeneity and lack of standardised disassembly protocols [123,126,127]. Thus, this review extends prior general reviews (e.g., [16]) by mapping component-level knowledge gaps across 150 studies.

5.2.2. Institutional and Theoretical Evolution

The findings strongly support coercive isomorphism theory [156], as regulatory pressure emerges as the most influential enabler of RSC adoption [27,60,61,108]. Many firms initiate RSC implementation primarily to comply with EPR mandates rather than through intrinsic strategic motivation [60,61,109].

Simultaneously, the field has evolved toward the Natural-Resource-Based View (NRBV) framework [157]. Earlier compliance-driven models are increasingly replaced by strategic capability perspectives, where organisations leverage reverse logistics as a competitive advantage [136]. Firms investing in modular design, digital traceability, and process innovation achieve superior environmental and financial performance [123,126,127,136].

This transition from compliance logic to capability logic represents one of the most significant conceptual contributions emerging from the aggregated 150-paper synthesis.

5.2.3. Technological Integration and Industry 4.0–5.0 Context

Across the dataset, digital technologies such as IoT, blockchain, AI-enabled predictive diagnostics, and digital twins are increasingly embedded within circular supply chain architectures [71,83,95,114]. These technologies mitigate information asymmetry, improve traceability, and optimise recovery decisions.

However, empirical validation remains limited. While simulation studies demonstrate efficiency improvements [71,83], large-scale industrial case studies confirming long-term viability remain scarce [154]. Thus, the digital–circular integration literature remains predominantly conceptual or model-driven.

5.3. Managerial and Policy Implications

5.3.1. Managerial Implications

The collective evidence from 150 studies suggests that organisations must adopt cross-functional strategic integration rather than isolated reverse logistics initiatives [62,63,65,136,149]. RSC should be treated as a strategic asset capable of generating economic value, environmental legitimacy, and competitive differentiation.

Firms must address the “scale–value tension” identified across multiple network optimisation studies [9,61,65,70,127,150,151]. Centralised processing maximises economies of scale for low-value materials, whereas decentralised specialised facilities enhance high-value component recovery. Hybrid network architectures appear most effective.

Investment in digital traceability systems such as blockchain-enabled product passports and IoT monitoring systems improves transparency and reduces uncertainty in component recovery markets [71,83]. However, firms must simultaneously address organisational resistance and cultural adaptation barriers [136].

5.3.2. Policy Implications

The review confirms that EPR frameworks function effectively when supported by stable regulatory signals and enforcement mechanisms [27,61,108]. Governments should design flexible, innovation-supportive regulatory architectures that reduce private investment risks [109].

In developing economies, the coexistence of informal and formal sectors presents both challenges and opportunities. Studies suggest integrating informal collection networks with formal environmental compliance systems to create inclusive circular ecosystems [108].

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Furthermore, harmonisation of global recycling standards and battery traceability regulations would improve international coordination and material recovery efficiency [35,102].

5.4. Limitations and Future Research Agenda

5.4.1. Expanding Component and Geographic Scope

The dataset demonstrates heavy concentration in EV batteries and Chinese case studies [35,137–145]. Future research should expand to:

- Automotive electronics and embedded systems
- Advanced lightweight composites
- Thermal management modules
- Rare-earth element recovery

Geographic expansion toward underrepresented regions (Middle East, Oceania, Americas, Africa) would improve contextual generalisability.

5.4.2. Human and Behavioural Dimensions

One of the most critical gaps identified across the 150 reviewed studies is the limited integration of behavioural and social science perspectives into automotive Circular Supply Chain (CSC) and Reverse Supply Chain (RSC) research [1–150]. Approximately two-thirds of quantitative modelling studies rely on rational decision-making assumptions, where consumers, managers, recyclers, and policymakers are treated as economically optimising agents operating under full information and stable preferences [39,95,114,119,120]. While analytically convenient, this assumption oversimplifies the complex behavioural drivers influencing return rates, remanufacturing adoption, and recycled product acceptance.

5.4.2.1. Consumer Behaviour and Product Return Decisions

Empirical evidence suggests that consumer participation in take-back systems is influenced not only by economic incentives but also by environmental awareness, perceived convenience, trust in recyclers, and social norms [39,119,120,153]. Studies examining EV battery return behaviour indicate that concerns regarding data security, safety risks, and residual value uncertainty significantly affect return timing and channel selection [71,137].

However, behavioural heterogeneity is rarely incorporated into network optimisation models. Most frameworks assume deterministic return rates or fixed stochastic distributions, failing to capture dynamic psychological and cultural influences [95,114]. This creates an overestimation of system efficiency in theoretical designs compared to actual implementation outcomes.

Future research should therefore integrate:

- Behavioural economics principles (bounded rationality, loss aversion, trust asymmetry)
- Social influence modelling (peer effects in green consumption)
- Cultural and regional value systems affecting circular participation

Mixed-method research designs combining experimental studies, field surveys, and behavioural simulations can generate more realistic recovery-rate estimations.

5.4.2.2. Managerial Cognition and Organisational Behaviour

Beyond consumer behaviour, managerial perceptions significantly shape RSC implementation. Several studies indicate that managers often perceive reverse logistics as a compliance obligation rather than a strategic opportunity, particularly in early adoption phases [60,61,136]. Organisational resistance to change, uncertainty about long-term ROI, and cross-functional misalignment create implementation inertia.

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Although the Natural-Resource-Based View (NRBV) [157] suggests that sustainability capabilities can create competitive advantage, the transition from compliance-driven logic to capability-driven strategy requires cognitive transformation within firms [123,126,136].

The review reveals that few studies empirically investigate managerial decision-making biases, risk aversion, or leadership orientation toward circular transformation. This gap limits understanding of why theoretically optimal RSC configurations are often not adopted in practice.

Future research should explore:

- Top management commitment and sustainability leadership styles
- Organisational learning mechanisms in circular transformation
- Cultural barriers to cross-functional integration

Such inquiry would strengthen the micro-foundations of circular supply chain theory.

5.4.2.3. Social Equity and Informal Sector Dynamics

Particularly in developing economies, informal collection networks play a substantial role in material recovery [108]. Yet most optimisation models exclude social equity considerations and labour conditions. Integrating informal actors into formal circular systems requires governance structures that balance efficiency with social protection.

The triple bottom line perspective (economic, environmental, social) is frequently cited but rarely operationalised quantitatively [72,88]. Future research should develop metrics that measure social sustainability outcomes alongside financial and environmental performance.

5.4. Bridging the Theory–Practice Gap

The synthesis of 150 studies demonstrates a clear divergence between theoretical sophistication and practical applicability. The proliferation of game-theoretic models, multi-objective optimisation algorithms, and stochastic programming approaches has significantly advanced academic rigor [95,114,150,151]. However, empirical validation remains comparatively limited [154].

5.4.1. Overemphasis on Model Optimality

Many network design studies identify mathematically optimal facility locations, recovery flows, and pricing strategies under idealised assumptions [9,65,70,127]. While these models offer conceptual clarity, real-world implementation is constrained by regulatory uncertainty, behavioural variability, capital constraints, and technological incompatibilities.

Industry case studies reveal that practical deployment often deviates from model prescriptions due to:

- Data unavailability or inaccuracy
- Infrastructure limitations
- Political or stakeholder resistance
- Contractual and coordination complexities

Thus, optimisation-based findings frequently lack translational mechanisms for managerial application.

5.4.2. Limited Longitudinal and Implementation Studies

Only a small proportion of reviewed papers adopt longitudinal case study methodologies tracking RSC implementation over time [136,154]. Most empirical contributions rely on cross-sectional survey data or simulated datasets.

To bridge this gap, future research should prioritise:

- Action research collaborations with automotive OEMs
- Pilot project evaluations of digital traceability systems
- Long-term performance tracking of hybrid circular networks

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- Comparative case analyses across regulatory environments

Such approaches would generate practice-grounded theory and refine existing optimisation models using real-world feedback loops.

5.4.3. Digital Transformation and Operational Reality

Although numerous studies advocate Industry 4.0 technologies—IoT-enabled tracking, blockchain-based product passports, AI-driven diagnostics—as enablers of circularity [71,83,95], practical scalability challenges persist.

Implementation barriers include cybersecurity concerns, interoperability issues, high upfront investment, and lack of standardisation. Without systematic pilot validation and cost–benefit evaluation, digital-circular integration risks remaining aspirational rather than operational.

Bridging the theory–practice gap therefore requires interdisciplinary integration across operations management, information systems, behavioural science, and public policy.

5.4.4. Temporal and Journal Limitations

5.4.4.1. Temporal Scope Constraints

This review covers publications from 2014 to the end of 2024 to ensure complete annual datasets and consistent longitudinal trend analysis [1–150]. However, the rapid acceleration of EV adoption, battery innovation, and regulatory reforms in 2025 onward may introduce emerging themes not captured within this timeframe.

For example:

- Solid-state battery recovery challenges
- Digital product passport mandates
- Industry 5.0 human-centric manufacturing frameworks

Thus, while the 2014–2024 window provides robust maturity analysis, the dynamic nature of circular automotive systems necessitates periodic updates to maintain relevance.

5.4.4.2. Journal Ranking and Database Selection Bias

To ensure academic rigor, this review primarily includes Q1–Q2 indexed journals and peer-reviewed conference proceedings [24]. While this enhances methodological robustness and citation reliability, it may inadvertently exclude:

- Regional journals publishing context-specific case studies
- Non-English publications
- Emerging interdisciplinary outlets
- Practitioner-focused industry reports

Such exclusion may bias findings toward developed economies and well-established research communities.

Future reviews should consider:

- Expanding database coverage (including Scopus, Web of Science, regional indices)
- Incorporating grey literature where methodologically sound
- Including industry white papers for applied insight

5.4.4.3. Evolving Interdisciplinary Boundaries

Automotive circularity research increasingly intersects with materials science, behavioural economics, digital governance, and sustainability policy. Strict journal filtering may limit interdisciplinary breadth. Future systematic reviews should adopt broader thematic inclusion criteria to capture these cross-domain developments.

Integrated Insight

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The expanded analysis of Human and Behavioural Dimensions, Theory–Practice Gaps, and Temporal/Journal Limitations reveals that the next stage of automotive circular supply chain research must move beyond optimisation dominance toward:

- Behaviourally informed system design
- Empirically validated implementation frameworks
- Interdisciplinary integration
- Broader geographic and publication inclusivity

Only by incorporating human decision-making realities, long-term deployment evidence, and evolving regulatory-technological contexts can the field transition from theoretical advancement to globally applicable circular transformation.

6. Conclusion

This review synthesizes the existing body of literature to provide an integrated understanding of reverse and circular supply chain (RSC/CSC) practices in the automotive sector. The field has evolved considerably over time. Earlier contributions largely concentrated on operational efficiency, facility location planning, and cost optimization in reverse logistics systems [1–38]. More recent studies demonstrate a transition toward strategic, sustainability-oriented, and system-level perspectives that incorporate circular economy principles, environmental performance measurement, and regulatory alignment [39–95].

Operations and supply chain design remain central pillars of circular implementation, forming the structural backbone of recovery and remanufacturing systems [1–38]. At the same time, sustainability and environmental performance have become dominant research streams, with strong emphasis on lifecycle assessment, emission mitigation strategies, and resource efficiency across electric vehicle (EV) and end-of-life vehicle (ELV) systems [39–69]. The growing focus on circular economy and reverse logistics highlights the increasing importance of remanufacturing, recycling infrastructure, and second-life applications, particularly in battery systems [70–95].

EV battery recovery has emerged as one of the most technically and strategically complex domains. Studies underline the need for differentiated recovery architectures, robust quality assessment mechanisms, and advanced [39–95systems to manage state-of-health uncertainty and residual value extraction [96–128]. In contrast, bulk materials such as metals tend to follow centralized, scale-driven processing structures focused on cost efficiency and throughput optimization [70–95]. This contrast illustrates a structural "scale–value tension" within reverse supply chains, where high-volume materials prioritize economies of scale while high-value components require flexible, decentralized coordination [96–115].

Geographically, the literature reflects strong contributions from rapidly industrializing economies, particularly in Asia, alongside significant input from European countries operating under structured regulatory frameworks such as Extended Producer Responsibility (EPR) [129–138]. However, relatively limited representation from certain regions indicates potential contextual gaps and the need for broader cross-regional investigation [139–150]. These disparities suggest that existing models may not fully capture institutional, socio-economic, and infrastructural diversity.

Methodologically, quantitative modelling dominates the field, including mixed-integer linear programming, multi-objective optimization, and game-theoretic coordination models [96–115]. While these approaches provide analytical rigor and structural clarity, several studies highlight the gap between theoretical optimization and practical implementation due to behavioural complexity, managerial constraints, and policy uncertainty [139–150]. Greater integration of qualitative insights, case-based evidence, and mixed-method designs is therefore necessary to enhance real-world applicability.

The theoretical trajectory of the field reflects a movement from compliance-driven reverse logistics toward strategic circular capability development. Organizations increasingly recognize circular supply chains as sources of competitive advantage, innovation, and long-term value creation

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rather than mere regulatory obligations [116–138]. Simultaneously, policy instruments—including carbon regulation, EPR mechanisms, and sustainability standards—act as powerful institutional drivers shaping firm behaviour and technological investment decisions [129–138].

Managerially, the evidence supports the adoption of hybrid recovery networks that combine centralized efficiency for low-value material flows with decentralized, quality-sensitive systems for high-value components [70–115]. Digital technologies such as IoT-enabled monitoring, blockchain-based traceability, and predictive analytics play an enabling role in reducing information asymmetry and strengthening coordination across supply chain actors [116–128]. Policymakers, in turn, must design stable and adaptive governance systems capable of encouraging innovation while minimizing investment risks [129–138].

Despite notable advancements, several research gaps remain. There is a strong concentration on EV battery systems, while other automotive components—including advanced electronics and composite materials—require deeper exploration [139–150]. Behavioural and social dimensions, particularly consumer participation, informal sector integration, and managerial decision-making processes, remain comparatively underdeveloped [139–150]. Addressing these gaps will be critical for building more inclusive, realistic, and implementable circular supply chain frameworks.

Overall, the literature demonstrates that automotive circular supply chain research has matured into a multidimensional and strategically significant domain. Future progress will depend not only on refining analytical models but also on broadening geographical scope, strengthening empirical validation, integrating behavioural perspectives, and fostering stronger alignment between theory and practice [139–150]. Through such advancements, the field can more effectively support the transition toward resilient, sustainable, and value-generating automotive ecosystems.

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