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Performance Assessment of Sustainable Reverse Logistics Networks: A Systematic Review

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Abstract: Reverse logistics (RL) in the manufacturing sector is of prime importance due to the implications of the increasing scarcity of raw materials and environmental concerns. It is concerned with product returns, refurbishing, recycling, and the disposal of end-of-life products. RL should be considered a strategic tool for implementing the strategic vision of the circular economy. Implementation of performance measurement systems in RL is thus instrumental to operational excellence, cost savings, customer satisfaction, and sustainability management for product returns and end-of-life products. The most critical variable that is normally considered in designing a sustainable reverse logistics network is service lifetime. This research carried out a systematic literature review on the performance assessment of the Reverse Logistics networks during the period 2019-2025. The aim is to enhance fruit and address some gaps of research areas. Data used in this study were extracted and filtered from the Web Science and Scopus databases. The results obtained from this literature survey are studied to understand different assessment approaches of performance of the reverse logistics assessment in many industrial applications. Moreover, some recommendations for future work paved the way for the researchers who are interested in this research area.

1. Introduction

Reverse Logistics (RL) plays a vital role in improving supply chain efficiency and leveraging for its competitive role in industrial and marketing regions. It involves various operations, including recycling, repair, and refurbishment, as shown in Table 1. This table introduces the different types of reverse logistics operations. The two most famous companies in the repair sector are Apple (Independent Repair Provider program), and Tesla (battery module-level repairs). Example of reuse and add value: Volvo's remanufacturing program reduces costs by 30% compared to new parts, and Cisco's refurbished gear sells at 40-60% discount, with 90% fewer emissions than new production.

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RL is essential for both enhancing customer satisfaction through smooth return procedures and promoting environmental sustainability by minimizing waste and carbon emissions, thus helping organizations to meet sustainability targets and environmental regulations [1],[2].

Table 1: Different types of reverse logistics operations

RL operation	Description
Remanufacturing	Remanufacturing involves rebuilding a product to its original specifications using a combination of reused, repaired, or new components [3],[4],[63]. For example of added value an automotive company adds value by recovering used engines and determines that 70% of the components can be reused. Mercedes-Benz, Ford Motor Company, BMW Group, similarly, In electronics, high-end remanufactured MacBook's, iPads, and iPhones with a warranty. Such as HP, Dell, and Apple.
Product Recycling.	Recycling is extracting raw materials (metals, plastics, glass) from end-of-life products to reintroduce them into the manufacturing process. Examples of added values in the plastic sector such as P&G (Procter & Gamble), (Head & Shoulders recycled shampoo bottles) and in the textile sector, such as H&M (Garment collection and fibre regeneration) [5],[6],[65],[67].
Repair	Repair operation concerns about extending of product's end-of-useful life period by patching up existing products, which gives customers the maximum value for the products they buy. [7],[8],[66]. Added values in using of genuine parts or increases product longevity and performance. Example company: Apple (Independent Repair Provider program), and Tesla (battery module-level repairs).
Refurbishment	It involves cleaning the repairing failed components in product. Added value appear in enhancing product performance. Example company IKEA (Refurbished furniture sales show 28% higher profit margins than new products in Scandinavian markets) and Caterpillar (Complete machine refurbishment restores 95% of original performance at 55% of new equipment cost)[9],[10],[66].
Reuse	Reuse is the process of using a material or product or part of it, either for its actual usage or to meet the requirements of a different product [11],[12],[62][63],[64]. Example of add values: Volvo's remanufacturing program reduces costs by 30% compared to new parts and Cisco's refurbished gear sells at 40-60% discount, with 90% fewer emissions than new production.

Key Performance Indicators (KPI's) in the RL's is very important for organizations to identify the best ways to optimize RL processes, reduce costs, and waste management [13], [14], [61]. The most common KPI's are listed in Table 2. The table presents the performance indicators KPI's, the relationships on the basis of which these indicators are calculated, and the significance of the calculated values. As sustainability is considered as an integral part of the strategy of a successful organization, through the ability to respond to the new strategies developed out of challenges faced from the Environment, society, and economy. The performance of sustainability aspects must be measured and monitored through KPI's [15], [16]. Environmental KPI's relate to the measurement of the impact of an organization on the environment, while Social KPI's establish the impact an organization makes on its employees, society, and the community, but economic KPI's reflect the economic impact of the sustainability performance [17],[18] as shown in Table 3. This table introduces some examples of sustainable RL process KPI's. The indicators are divided into three key performance indicators: economic key performance indicators, social key performance indicators, and environmental key performance indicators.

The second part is the research methodology which applied on the research. The third part of the literature presents the previous literature reviews conducted for this study the fourth and fifth parts of the literature contain the results and conclusion of the previous literature reviews. These results contain gaps and findings that could be future points of research to improve and enhance the sustainability of supply chain reverse logistics.

Aims and contribution of this paper to propose an overview of different optimization models to solve the trade off and conflict the different natures and complexities of designing a sustainable reverse logistic network and improving green performance. Figure 1 shows the flow chart for the literature methodology.

Table 2: Reverse logistics KPI's

Reverse logistics KPI's	Formula	Explain
Returns and exchanges	(Quantity of returns ÷ Quantity of sold) × 100	High rates indicate product or customer experience issues. Investigate root causes like product quality or inaccurate descriptions.
Recovery rate	(Recovered value ÷ Total returns) × 100	Low recovery suggests inefficient refurbishment processes. Partner with specialized refurbishes to maximize value.
Disposition cycle time	Average days to assign disposition	Slow processing increases holding costs. Implement automated inspection systems to accelerate decisions.
Cycle time for returns processing	Days from request to resolution	Delays hurt customer satisfaction. Streamline workflows and consider prepaid return labels.
Cost per return / reverse shipment	Total RL costs ÷ Quantity of returns	High costs indicate inefficiencies. Negotiate carrier rates or establish regional return centres.
Scrap rate	(Quantity of scrapped ÷ Quantity of returns) × 100.	Excessive waste suggests poor sorting or design. Implement better disassembly processes and recycling partnerships.
Sustainability KPI's (Carbon reduction, waste diverted)	CO_2 emission saved ÷ Total returns	Low savings indicate missed opportunities. Prioritize refurbishment over recycling when possible.

2. Methods and tools

RL networks have rapidly evolved from 2019 to the second quarter of 2024, necessitating a systematic literature review to synthesize methodologies for assessing performance in sustainable RL networks. Utilizing prominent academic databases—Science Direct, Scopus, and Web of Science (see Table 4) alongside supplementary sources (33 cross-referenced documents, 25 manual searches, and 9 expert recommendations), six refined search queries were employed, combining terms such as "reverse logistics" and "performance" and "end-of-life products" and "reverse logistics", with quotation marks retained to ensure precision and avoid generic results. Initial searches yielded 997 documents, supplemented by 55 additional sources, culminating in 1,036 records after duplicate removal. A two-step selection process was implemented: titles, abstracts, and keywords were screened to exclude 971 irrelevant studies, followed by a full-text review of 68 articles, with 6 excluded for lacking methodological rigor or misalignment with the research scope, resulting in a final corpus of 65 articles. To mitigate bias, two authors independently conducted screening and analysis, resolving discrepancies through consensus. The selected studies were categorized by author, country, keywords, publication year, and methodology. Figure 2 shows the election of related articles flow chart.

Table 3: Examples of sustainable RL process KPI's

Type of KPI's	KPI's	Formula	Description
Environmental KPI's	% of carbon emissions	Total CO_2 emissions ÷ Production units	Measures climate impact per item. Example: renewable energy to reduce and optimize logistics routes to cut emissions.
	% of waste reduction	(Recycled + reused waste) ÷ total waste × 100	Shows circularity progress. Partner with recycling facilities to improve.
	% natural resource usage or renewable vs. non-renewable sources	Water used ÷ units produced	Tracks resource intensity. It can be improved by installing water recycling systems.
Social KPI's	% of satisfaction of the worker	(Number of positive survey responses ÷ total) × 100	Indicates workplace health. Can be improved by flexible work policies. Conduct quarterly pulse surveys.
Economic KPI's	% of costs saved through sustainability initiatives	(Pre-initiative cost - post-initiative cost) ÷ pre-initiative cost × 100	Proves sustainability pays. Example: LED lighting cuts energy bills by 20% and Packaging redesign can reduce material costs
	% return on investment (ROI)	(Net profit from project ÷ Project cost) × 100	Justifies eco-investments. Case: EV fleet pays back in 3 years via fuel savings.

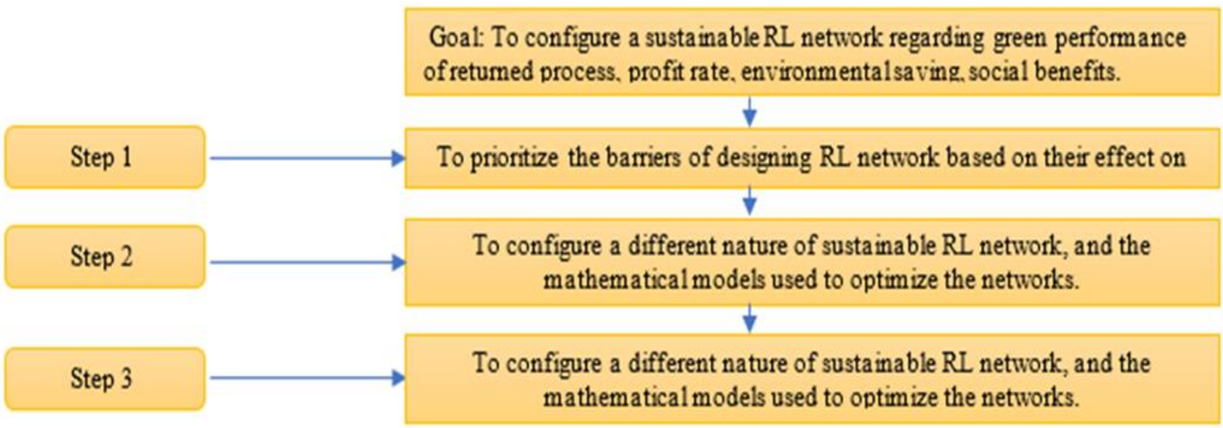

Fig. 1: Flow chart for the literature methodology.

Table 4: Summary of literature survey search results and selection process for RL studies

Search string	Database	Initial results	Cross-referenced	Manual searches	Expert recommendations	Duplicates removal	Selected articles
"Reverse logistics" and "performance"	Science Direct	320	10	7	3	340	26
"End-of-life products" and "reverse logistics"	Scopus	380	9	6	3	398	22
"Reverse logistics" and "sustainability"	Web of Science	291	8	5	2	306	19
Total	All	991	27	18	8	1,044	67

3. Results of methodology

From the analysis of the literature survey, a general conclusion can be represented by application area (see Figure 3), by year of publication (see Figure 4), and publication by country (see Figure 5). From Figure 3 it can be noticed that the highest number of publications in the electronics industry while the lowest number of studies is in the textile industry. From Figure 4 the publications through year 2024 were the highest while it was the lowest before year 2020.From Figure 5 publications in China and UK and Iran were represented the highest one while the smallest number of studies where in the third world countries.

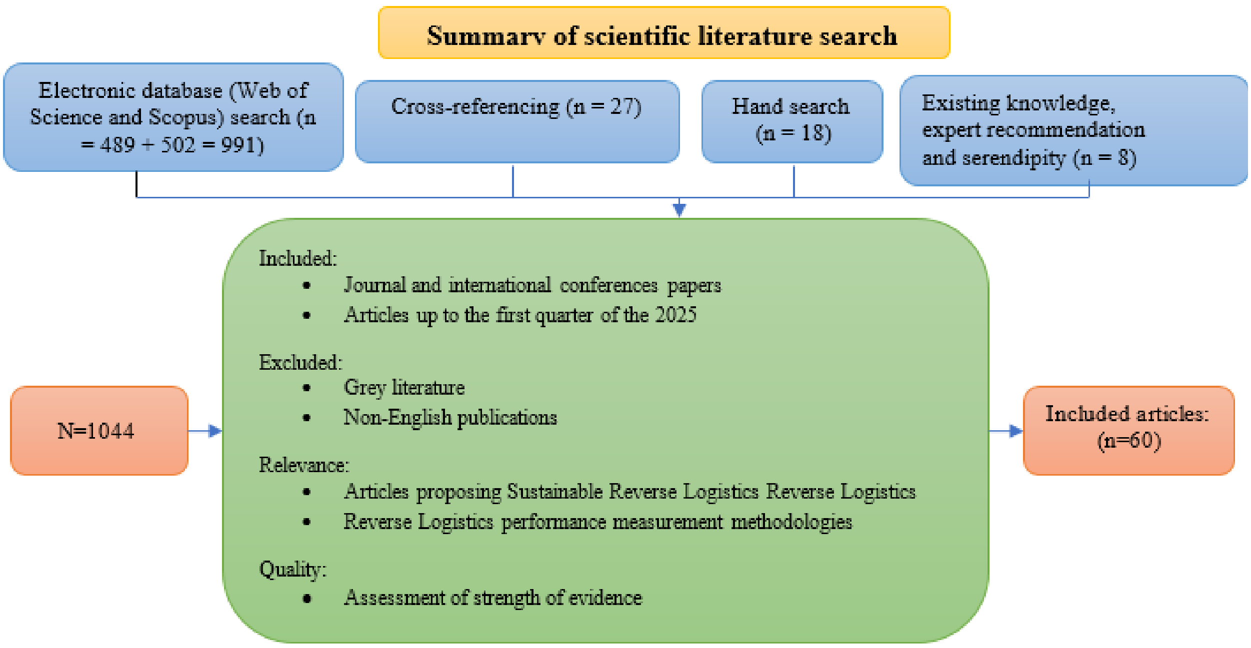

Fig. 2: Summary of the selection process of the related articles

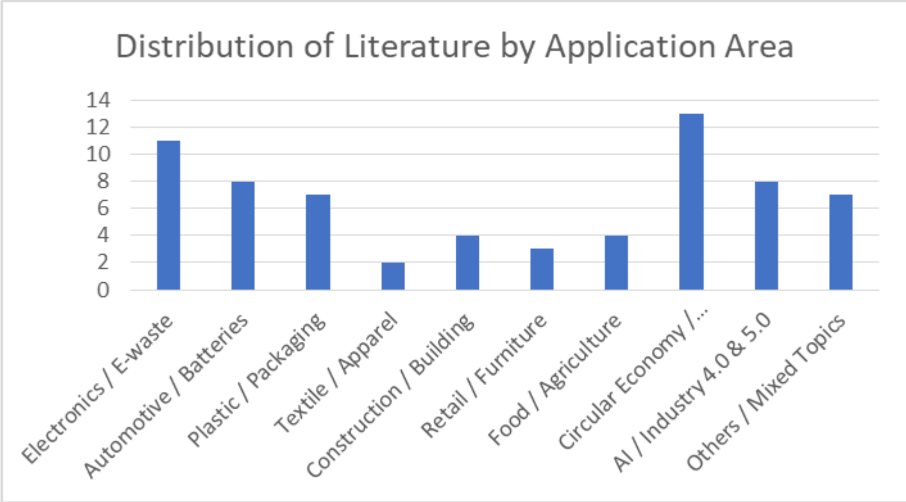

Fig. 3: Distribution of literature by application area

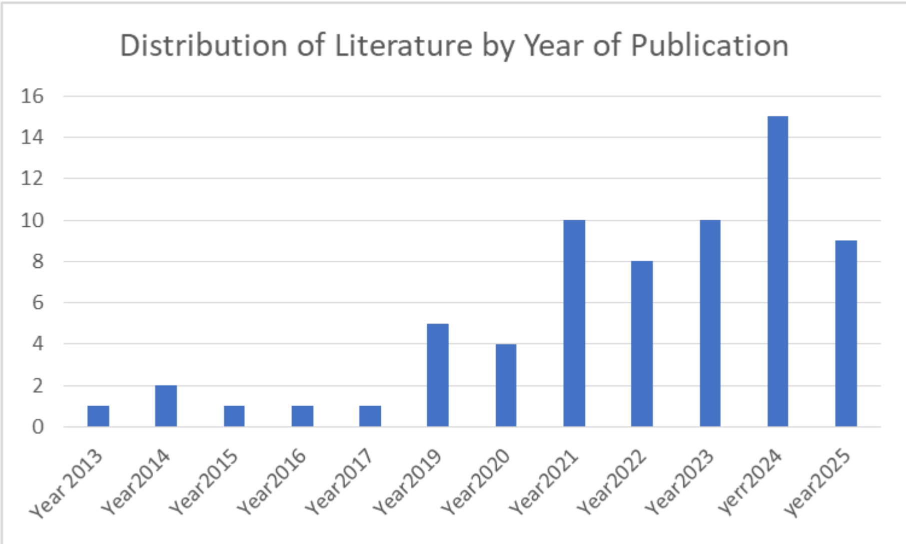

Fig. 4: Distribution of literature by year of publication

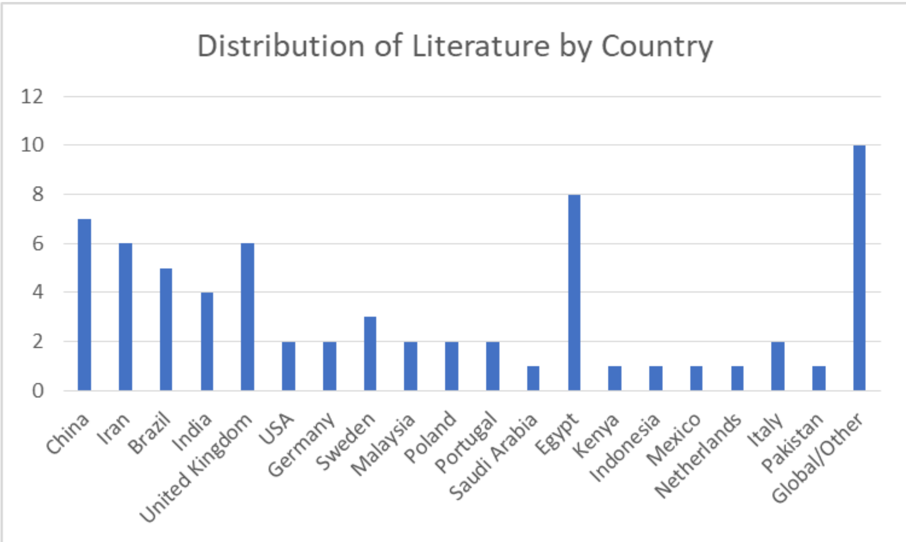

Fig. 5: Distribution of literature by country

4. Literature review outcomes

The literature review outcomes are divided into two main sectors; the first one is an overview of barriers and complexities that could be faced in designing sustainable reverse logistics. The second part about sustainable reverse logistics (RLs) design and all contact lines to that subject, such as: -

- Some optimization models with a different sector and,
- Some methodologies are used to design a sustainable reverse chain.
- The data analysis and key findings insight through the study of the literature survey and,
- The key gaps and recommendations

Thus, to help the decision makers and stakeholders reach a highly effective and most efficient sustainable reverse logistics design network in their supply chain.

4.1 Challenges in designing sustainable reverse logistics

Implementation of reverse logistics design is a critical step toward achieving sustainable and efficient supply chain operations. However, organizations often face several challenges that hinder the successful adoption of reverse logistics practices. These barriers can be related to financial, organizational, technological, or regulatory factors. Understanding these obstacles is essential for developing effective strategies that support reverse logistics implementation.

Table 5 summarizes the most common barriers encountered in the design and execution of reverse logistics systems. An understanding of the barriers hindering the implementation of reverse logistics design is essential for improving operational aspects of the RL process.

Table 5: Barriers to implementing RL's Design

Barrier Cluster	Paper	Objectives	Methodology	Sub-Barriers
Economic Barriers	[19], [20]	-Quantify financial impediments to RL adoption - Analyse cost-benefit trade-offs	- Hybrid modified SWARA-WASPAS approach - Integrated cost modelling	- High initial infrastructure costs - Uncertain return on investment - Lack of government incentives
Regulatory Barriers	[21],[22]	- Examine policy constraints across industries - Identify compliance challenges	- MCDM analysis - ISM-MICMAC matrix	- Complex documentation requirements - Lack of standardized global policies - Restrictive cross-border regulations
Operational Barriers	[23],[24]	- Assess supply chain execution hurdles - Evaluate process inefficiencies	- System dynamics modelling - Systematic literature review	- Poor coordination with suppliers & - Inadequate collection infrastructure - Inventory management challenges

Barrier Cluster	Paper	Objectives	Methodology	Sub-Barriers
Technological Barriers	[1], [2]	- Evaluate digital transformation gaps - Assess tracking capabilities	- Benchmarking analysis - Performance assessment framework	- Legacy system incompatibility - Lack of IoT integration - Data silos across partners
Cultural Barriers	[20],[23]	- Analyse human resistance factors - Measure awareness gaps	- Integrated qualitative approach - Thematic analysis	- Employee resistance to change - Low consumer participation - Lack of a green mindset

***SWARA** = *Stepwise Weight Assessment Ratio Analysis*
***WASPAS** = *Weighted Aggregated Sum Product Assessment*
***MCDM** = *multi-criteria Decision-Making*
***ISM** = *Interpretive Structural Modelling*
***MICMAC** = *Cross-Impact Matrix Multiplication Applied to Classification*

These barriers are multi-dimensional, affecting economic planning, regulatory compliance, operations, technology adoption, and cultural readiness. To support more effective reverse logistics systems, researchers have identified key research gaps and proposed targeted solutions. The following Table 6 provides a categorized analysis of these barriers, highlighting existing research gaps, suggested solutions from the literature, and practical recommendations tailored to various stakeholders.

Table (6): Analysis for the barriers of implementing RL’s design

Barrier Category	Gaps in Research Identified	Proposed Solutions from Literature
Economic	Limited dynamic ROI models [19] Few studies on SME financing [20]	Blockchain-based cost tracking [20] Public-private investment pools [19]
Regulatory	Minimal construction sector analysis [22] Lack of global policy comparisons [21]	Digital compliance platforms [21] Industry-specific policy frameworks [22]
Operational	Food RL metrics underdeveloped [24] Cold chain research scarce [25]	Smart packaging with sensors [24] Automated sorting systems [25]
Technological	AI applications rarely tested [1] Digital twin case studies missing [25]	Cloud-based RL platforms [1] Predictive analytics tools [25]
Cultural	Consumer behaviour studies are limited [23], Training impact unmeasured [20]	Gamified return programs [20] Circular economy education [23]

Identifying the barriers to reverse logistics implementation requires the use of diverse and robust research methodologies. Both qualitative and quantitative techniques are used to analyse these challenges across different sectors. Each method offers unique strengths, limitations, and levels of applicability depending on the context. The following table 7 summarizes the methodologies used in key studies, indicating their sectoral application, frequency of use, and notable observations. This overview helps in understanding how various analytical tools contribute to the exploration of reverse logistics barriers and enhancing the effectiveness of operational RL processes in industry.

Table 7: Outcomes of methodologies used to identify barriers of RL's in the survey

Methodology	Papers Using It	Sectors Used	Usage% (Across Papers)	Recommendations
Systematic Literature Review (SLR)	[23],[25],[1]	General industries, Reverse supply chains, Circular economy	37.5% (3/8 papers)	Good for theory building but weak in direct application
Integrated DEMATEL and ISM	[20]	Circular Economy (Textiles, Electronics)	12.5% (1/8 papers)	Good for finding cause-and-effect barriers, but complex
MCDM (multi-criteria Decision-Making)	[21]	Closed-loop Supply Chains (Automotive, Electronics)	12.5% (1/8 papers)	Good for multi-barrier ranking
Hybrid SWARA and WASPAS	[19]	General RL (Consumer goods, e-waste)	12.5% (1/8 papers)	Highly practical ranking method but subjective risks
ISM and MICMAC	[22]	Construction (waste recycling, demolition)	12.5% (1/8 papers)	Powerful for construction-specific complexity
System Dynamics Simulation	[24]	Food supply chains (cold chain, perishables)	12.5% (1/8 papers)	Very strong dynamic model, data-sensitive

4.2 Sustainable RLs design

Designing sustainable reverse logistics (RL) systems involves multiple interdisciplinary domains that contribute to economic, environmental, and operational goals. Recent research has clustered these domains into thematic areas to better understand the strategic focus of sustainable RL design efforts. These clusters highlight the integration of circular economic principles, digital technologies, performance metrics, and legal frameworks, among others. The following Table 9 presents an overview of the major research clusters identified in the literature, along with the corresponding studies and a brief description of each domain's contribution to sustainable reverse logistics design.

Table (9): Clusters of the domains used by the survey in sustainable RLs design

Cluster Number	Clusters	Papers No.	Descriptions
1	Circular Economy and Electric Vehicles	[26],[27] , [28]	Circular economy strategies for EVs and electronics.
2	Reverse Logistics & Network Design	[29], [30], [25], [31], [27], [32], [33], [34], [35], [36], [37], [38],	Network design and frameworks for reverse logistics under different contexts.
3	Sustainability KPIs and Performance Measurement	[39], [26], [40] , [41], [42], [31], [43], [44]	Impact of reverse logistics and sustainability KPIs on business practices and policies.
4	Industry 4.0 / 5.0 Technologies and Digitalization	[45], [46], [47], [48],[32] ,[49] ,[50] , [51], [52], [26], [38]	Role of digital transformation (Industry 4.0/5.0, AI, Big Data) in circular and reverse logistics.
5	Optimization and Modelling for Reverse Logistics	[42], [53], 38, [33], [54], [33],[34] , [35], [55], [36], [37], [37], [56], [28], [1]	Mathematical modelling, multi-objective optimization, system dynamics models.
6	Case Studies and Applications	[39], [42], [27], [54], [33],[34] , [44], [1], [28]	Empirical case studies in food, e-waste, EVs, tea industry, etc.
7	Legal and Policy Perspectives	[41], [42], [44]	Regulatory, legal, and techno-political frameworks for sustainability and reverse logistics.

To understand the contributions of practical implications in sustainable RL design, it is essential to analyze the strengths, limitations, and methodological approaches used within each thematic research cluster. This step enables decision makers and stakeholders to identify well-established, where knowledge gaps remain, and how future research and policy can be directed. The following Tables 10 to 16 provide a detailed breakdown of each cluster previously identified, highlighting their methodological foundations, observed strengths, existing research gaps, and tailored recommendations for researchers, industry practitioners, and policymakers.

Table (10): Outcomes of cluster (1)

Key findings	Paper [26]	Paper[27]	Paper[28]
Strengths	- Comprehensive systematic literature review. - Clear mapping of CE strategies in EV sector (design, recycling, reuse). - Highlights business model and technology innovation needs.	- Innovative use of Gompertz model for predicting waste flows of EV and electronic products. - Focuses on quantitative forecasting for circular economy management.	- Proposes a multi-level reverse logistics network. - Integrates uncertainty modelling (returns, demand) into network design. - Strong environmental and operational optimization.
Gaps	- Lacks empirical validation or case studies. - Limited focus on policy integration and regional variations. - Technology readiness issues identified but not deeply explored.	- Model is highly theoretical. - Practical implementation issues, such as cost or regulatory challenges, are not addressed. - Focus limited to waste quantity prediction, less on infrastructure.	- Limited exploration of policy drivers and incentives. - Assumes some stable parameters (e.g., battery quality) that in real life can vary. - Lacks consumer behaviour factors influencing battery return rates.
Methodologies	- Systematic Literature Review (PRISMA-based method). - Thematic categorization: design, production, use, end-of-life strategies.	- Mathematical modelling using Gompertz curve. - Lifecycle prediction based on historical sales and technology penetration rates. - Data-driven simulations.	- Mixed-integer linear programming (MILP) for network optimization. - multi-stage reverse logistics planning under uncertainty. - Sensitivity analysis of key parameters.
Recommendations	- Future research should involve case-based studies and pilot projects. - Promote policy frameworks to speed up CE adoption in EVs. - Strengthen cross-sector collaborations (e.g., between carmakers and recyclers).	- Extend models to incorporate economic feasibility and environmental impact assessments. - Validate the Gompertz model using real-world waste data. - Link predictive models with supply chain design.	- Include policy instruments (e.g., subsidies, penalties) into model scenarios. - Account for user incentives to increase collection rates. - Adapt models to multi-country or regional supply chains for global EV markets.

Table (11): Outcomes of cluster (2)

Dimension	Key Findings Across Papers
Strengths	- Strong focus on network optimization for reverse logistics under sustainability and circular economy goals. - Application of multi-objective and multi-criteria models to balance costs, environment, and service quality (Papers [54], [37], 60). - Consideration of uncertainties (demand, returns) in network design (Papers[32],[36]). - Introduction of digitalization (Industry 5.0 concepts) for enhancing reverse flows (Papers[32],[27]). - Diverse application areas: e-waste, plastics, food waste, electronics, tires, batteries (Papers[31], [27], [34],[35]).

Dimension	Key Findings Across Papers
Gaps	- Most models are highly theoretical with few real-world validations. - Policy and regulatory aspects are rarely integrated directly into network models (except partially in Paper[31]). - Consumer behaviour and collection incentives are underexplored. - Few studies address globalized reverse logistics systems, mostly regional focus. - Limited use of real-time data for dynamic optimization.
Methodologies	- Mathematical modelling: Mixed-Integer Linear Programming (MILP), Robust Optimization, Multi-Objective Optimization (Papers [54], 47, [37],[28]). - Simulation-based approaches for network performance evaluation (Papers[29],[38]). - Systematic Literature Review for trends identification (Papers[30],[25]). - Data-driven forecasting combined with logistics network design (Paper[27]). - Case study applications: E-waste (Paper[31]), Tires (Paper[33]), Food waste (Paper[34]), Plastics (Paper[35]).
Recommendations	- Combine reverse logistics models with real-time IoT data and AI-based predictions (dynamic optimization). - Include policy frameworks (e.g., take-back laws, recycling incentives) into model constraints. - Develop consumer-centric collection strategies integrated into network models. - Broaden analysis to multi-country reverse logistics systems, especially for electronics and EV batteries. - Increase use of hybrid methodologies — combining optimization + simulation + life-cycle assessment (LCA) for holistic evaluation. - Promote pilot projects with industry collaborations to validate theoretical models.

Table (12): Outcome of cluster 3

Paper	Objective	Methodology	Strengths	Gaps	Case/Sector Study	Recommendations
[39]	Develop a sustainability KPI framework for reverse logistics.	Literature Review + Analytical Hierarchy Process (AHP).	Structured KPI hierarchy; prioritization through AHP.	No real-world validation; relies on expert judgment only.	General reverse logistics sector.	Pilot the KPI framework in live reverse logistics systems to refine indicators.
[26]	Assess green supply chain performance via KPIs.	Systematic Literature Review + Statistical Analysis.	Comprehensive collection of green KPIs; quantitative trend analysis.	Static analysis; lacks predictive performance tools.	Multi-sector green supply chain studies.	Develop predictive KPI models using AI/machine learning approaches.
[40]	Create a dynamic performance measurement system for sustainable logistics.	Balanced Scorecard (BSC) extension for sustainability + conceptual modelling.	Integrates financial, environmental, and social indicators dynamically.	No empirical application provided.	Sustainable logistics sector (conceptual).	Apply the extended BSC model in logistics companies for field testing.
[41]	Examine regulatory influence on sustainabilit	Policy analysis + qualitative interviews.	Unique regulatory perspective integrated	Limited quantitative validation; mainly	Logistics policy environment.	Conduct quantitative impact studies comparing

Paper	Objective	Methodology	Strengths	Gaps	Case/Sector Study	Recommendations
	y KPIs in logistics.		into KPI design.	qualitative insights.		regions with different regulations.
[42]	Propose a standardized framework for sustainability KPIs under techno-political settings.	Framework development via the Delphi Method.	Multi-stakeholder, consensus-driven framework.	Regional focus limits global applicability.	Regional logistics case studies (Europe-focused).	Broaden the framework to global contexts and emerging economies.
[31]	Identify key factors affecting sustainable reverse logistics KPIs.	Empirical study using Structural Equation Modelling (SEM).	Strong empirical grounding: causal relationships identified.	Single-country study; limited generalization.	Electronics reverse logistics sector (Country-specific).	Conduct multi-country comparative studies to validate results.
[43]	Develop sector-specific KPIs for sustainable waste management logistics.	Case study method + participatory workshops.	Practical, actionable KPIs with stakeholder involvement.	Context-specific; harder to generalize.	Waste management and recycling logistics.	Create adaptable versions of KPIs for different geographic or sectoral conditions.
[44]	Integrate legal and policy frameworks into sustainability performance measurement.	Legal analysis + policy benchmarking across countries.	Strong focus on policy-driven performance standards.	No quantitative KPI development; purely qualitative.	Comparative study of European Union vs. North American legal contexts.	Combine legal benchmarking with quantitative sustainability scorecards.

Table (13): Outcomes of cluster 4

Paper No.	Methodology	Strengths	Gaps	Sector/Case Study	Objectives	Recommendations
[45]	Systematic Literature Review	Comprehensive coverage of Industry 4.0 drivers/barriers	Limited empirical validation	Manufacturing SMEs	Map Industry 4.0 adoption roadmap	Conduct large-scale empirical studies

Paper No.	Methodology	Strengths	Gaps	Sector/Case Study	Objectives	Recommendations
[46]	Literature Review	Emerging trends identification; conceptual frameworks	No sector-specific validation	Sustainable Supply Chains	Explore trends/future directions of Industry 4.0	Sector-specific case studies needed
[47]	Conceptual Framework	Link between Industry 4.0 and Circular Economy	Lack of real-world testing	Circular Economy Initiatives	Propose collaborative framework	Test collaboration models in practice
[48]	Model Development + Case Application	Integrated methodology for Industry 5.0	Early-stage conceptual work	Reverse Logistics Flows	Enhance reverse logistics in Industry 5.0	Develop mature models with broader application
[57]	Literature Review	Merges Triple Bottom Line with Industry 5.0	Mostly theoretical	Supply Chain Management	State-of-the-art overview on sustainability	Move towards operational frameworks
[32]	Integrated MCDM Models (AHP, TOPSIS)	Strong quantitative approach	Context-specific (limited generalizability)	Supply Chain 5.0	Build sustainable & resilient enterprises	Validate model across industries
[32]	Uncertain Optimization Models	Addresses uncertainty in network design	High complexity, practical application unclears	Remanufacturing/ Reverse Logistics	Design Industry 5.0-ready reverse networks	Simplify models for real-world usability
[49]	Conceptual + Case Examples	Use of AI & Big Data in reverse logistics	High-level abstraction	Waste & Resource Management	Enhance logistics through AI & Big Data	Develop full pilot projects
[50]	Simulation and Smart Layout Design	Practical approach to reconfigurable manufacturing	Single-case design	Smart Manufacturing Systems	Smart layout design for flexibility	Expand simulations to other sectors
[51]	Systematic Literature Review	Deep dive into a digital transition of	Lacks case study validation	Digital Remanufacturing	Clarify pathways of digital transition	Empirical field validation

Paper No.	Methodology	Strengths	Gaps	Sector/Case Study	Objectives	Recommendations
		remanufacturing				
[52]	Review Paper	Early mapping of Industry 4.0 technologies in remanufacturing	Becoming outdated (pre-2020 insights)	Remanufacturing (General)	Survey emerging technologies	Update the review with recent technologies
[26]	Conceptualization & Research Agenda	Strong theoretical framing of Reverse Logistics 4.0	No empirical testing yet	Reverse Logistics 4.0	Define smart and sustainable transformation	Apply frameworks in practice
[38]	Conceptual Model + Review	Integration of Industry 4.0 and Circular Economy in green logistics	Conceptual, lacks applied testing	Green Logistics & Sustainable Supply Chains	Model green logistics systems	Pilot model in supply chain operations

Table (14): Outcomes of cluster (5)

Paper No.	Methodology	Gaps	Strengths	Sector / Case Study	Objectives	Recommendations
[42]	Conceptual framework + KPI modelling	Limited focus on uncertainty in RL networks	Connects reverse logistics with performance measurement	General industry	Develop performance KPIs for reverse logistics	Integrate digital tools for real-time KPI tracking
[53]	Network design optimization (MILP)	Simplified assumptions on returns variability	Strong mathematical modelling for network design	Electronics recycling	Optimize reverse logistics costs and flows	Model uncertainty and variable return rates
[58]	Multi-Objective Optimization (NSGA-II)	Lacks validation with industry data	Balances cost, time, emissions in RL	End-of-life vehicles	Optimize disassembly and recovery networks	Validate models through pilot projects
[1]	Game-theoretic modelling	Limited to duopolistic market structures	Innovative use of competitive models in RL	Waste electronics	Analyse competitive strategies in RL	Expand to multi-actor supply chains
[33]	Fuzzy MCDM + optimization	Model complexity may limit	Addresses uncertainty in return	General manufacturing	Decision support for selecting RL facilities	Simplify and adapt models for SME contexts

Paper No.	Methodology	Gaps	Strengths	Sector / Case Study	Objectives	Recommendations
		real-world application	rates and recycling			
[54]	Bi-objective optimization (genetic algorithms)	Lack of sensitivity analysis	Simultaneous cost and environmental minimization	Battery recycling	Optimize collection and recycling routes	Incorporate lifecycle cost analysis
[33]	Robust optimization	High computational intensity	Handles supply uncertainty well	Remanufacturing sector	Plan robust remanufacturing supply chains	Develop faster solution heuristics
[34]	Simulation modelling (Arena software)	Limited to operational-level analysis	Practical insight into warehouse operations	Electronic product returns	Optimize warehouse layout and returns processing	Extend simulation to strategic network levels
[35]	MILP + location-routing problem (LRP)	Static demand assumptions	Integrated logistics cost modelling	Pharma reverse logistics	Optimize return and disposal logistics	Introduce dynamic routing models
[55]	Stochastic programming	Data-heavy models	Incorporates random disruptions	Perishable goods	Design resilient reverse supply chains	Improve data acquisition methods
[36]	Petri nets for process modelling	Hard to scale for complex systems	Effective visualization of RL processes	Automotive remanufacturing	Model and optimize remanufacturing workflows	Hybrid Petri nets for complex scenarios
[36]	Multi-echelon inventory models	Basic return policies assumed	Comprehensive inventory + returns integration	Consumer electronics	Optimize reverse inventory control	Explore flexible return policies
[36]	Heuristic algorithms (Tabu Search, GA)	Not compared to exact solutions	Fast solution for large-scale RL problems	Electronics waste collection	Minimize total reverse logistics cost	Benchmark against MILP models
[37]	Mixed integer programming + multi-period planning	Assumes linear cost structures	Time-based planning strength	Battery recycling and disposal	Optimize RL network over multiple periods	Introduce non-linear cost structures
[56]	Markov decision processes (MDP)	Heavy mathematical complexity	Captures long-term uncertainty well	Vehicle parts remanufacturing	Dynamic control of product returns	Develop user-friendly decision tools
[28]	Hybrid optimization (GA + LP)	Needs more real-world	Flexibility in combining methods	Retail returns	Optimize logistics under	Collaborate with industries for model refinement

Paper No.	Methodology	Gaps	Strengths	Sector / Case Study	Objectives	Recommendations
		case validations			multiple objectives	
[1]	Reinforcement learning (RL) for logistics	Early-stage application, needs more training data	Innovative application of AI	Waste electronics	Real-time decision-making in RL	Develop large, realistic training datasets

Table (15): Outcomes of cluster (6)

Paper No.	Methodology	Gaps	Strengths	Sector / Case Study	Objectives	Recommendations
[39]	Survey + KPI framework application	Limited to specific industries; generalizability is low	Practical KPI system tested in real case	Electronics recycling sector	Develop and validate sustainability KPIs	Broaden validation across multiple sectors
[42]	Conceptual modelling + case illustration	High-level, lacks detailed operational modelling	Integration of KPIs into RL and sustainability	General industry example	Link performance measurement with reverse logistics	Develop sector-specific KPI standards
[27]	Case study approach (multiple companies)	Small sample size	Deep operational insights on practices	Electronics and automotive returns	Analyse success factors in RL systems	Expand sample for broader applicability
[1]	Game theory model applied to competitive case study	Duopolistic market assumption; oversimplified	Competitive dynamics captured realistically	Waste electronics (two major companies)	Model competitive behaviour in RL	Expand to oligopolistic/multi-player settings
[54]	Bi-objective optimization validated through case data	Static parameters; lacks dynamic factors	Demonstrated real trade-offs in case	Battery recycling supply chain	Optimize cost and environmental objectives	Introduce dynamic demand scenarios
[33]	Robust optimization + case study simulation	Computationally intensive	Real-world supply uncertainty handled	Remanufacturing logistics case	Design resilient supply chains under uncertainty	Develop faster, scalable robust models
[34]	Simulation (Arena software) of a warehouse operation	Focus only on micro-operational level	High operational realism	Electronics returns warehouse	Optimize warehousing for RL	Integrate with full supply chain simulations

Paper No.	Methodology	Gaps	Strengths	Sector / Case Study	Objectives	Recommendations
[44]	Legal and regulatory case analysis	Mostly descriptive; lacks quantitative depth	Comprehensive regulatory review	WEEE and automotive RL	Analyse impact of laws on reverse flows	Propose flexible regulatory frameworks
[28]	Hybrid heuristic optimization tested via case study	Needs larger case pool for full validation	Flexibility of combined GA and LP shown	Retail returns logistics	Optimize multi-criteria RL objectives	Broaden to more industries
[28]	Reinforcement learning applied on simulated RL environment	Early-stage; limited real-world testing	Innovative AI application to RL	Waste electronics RL system	Real-time adaptive decision-making	Test in live operational settings
[28]	Circular economy strategy case analysis (multi-company)	Focuses more on strategic, less on operational	Strong multi-sector perspective	EV batteries, consumer electronics	Promote CE strategies for end-of-life products	Detail operational implementation plans

Table (16): Outcomes of cluster (7)

Paper No.	Methodology	Gaps	Strengths	Sector / Case Study	Objectives	Recommendations
[41]	Policy framework analysis + conceptual modelling	No empirical validation; theoretical focus	Strong theoretical integration between RL and sustainability	General industrial reverse logistics (no specific sector focus)	Develop a regulatory framework supporting sustainable reverse logistics	Conduct empirical testing of proposed frameworks in different industries
[42]	Conceptual model linking KPIs to legal and policy requirements	Limited operational examples: mostly theoretical	Clear linkage between performance measurement and legal compliance	General, applicable across sectors	Bridge performance measurement systems with regulatory obligations in RL	Operationalize models in specific industries (e.g., electronics, automotive)
[44]	Comparative case study analysis of EU regulations (WEEE, ELV)	Focuses on European cases; limited to developed economies	Comprehensive review of legal and regulatory impacts on RL	Waste Electronics and End-of-Life Vehicles sectors	Examine how regulations affect RL system design and operations	Explore adaptable policy models for emerging economies

5. Results and Discussions

5.1 Main Sights in Barriers to Implementing the RLs Design Framework

- Most used methodology: Systematic Literature Review (SLR) = 37.5%
- Most powerful methodology (Practically): System Dynamics = Best real-world accuracy
- Best for sector-specific Applications:
- Construction → ISM (Interpretive Structural Modelling) beside MICMAC (Cross-Impact Matrix Multiplication Applied to Classification)
- Food supply chain → System Dynamics
- Circular economy adoption → Integrated DEMATEL (Decision-Making Trial and Evaluation Laboratory) beside ISM (Interpretive Structural Modelling).
- Literature Review is dominant but weak alone without combining real data.
- Model-based approaches: -DEMATEL (Decision-Making Trial and Evaluation Laboratory), ISM (Interpretive Structural Modelling), MCDM (Multi-Criteria Decision-Making) make more actionable results.
- Dynamic Simulation is the most advanced but requires deep expertise and good data
- **Dominant Barriers:** Economics (cited in 7/8 papers) and Operational (6/8 papers) barriers are most pervasive. The construction sector faces unique regulatory hurdles, while[22] food struggles with perishability [24].
- **Solution Trends:** Tech-driven: Block chain, AI, and IoT are proposed in 5/8 papers. Policy-driven: Standardization [23] and incentives [3] are critical.
- **Gaps in Research:** Behavioral barriers are understudied (papers [20] and [21] address consumer resistance). Global South focus: Only [23] and [7] include emerging economies.
- **Actionable Recommendations**
  - For Policymakers:

    Adopt "carrot-and-stick" policies (e.g., tax breaks + penalties) to address economic barriers [2]. Mandate circular design standards (e.g., the EU's Eco-design Directive) to stabilize secondary markets.
  - For Businesses:

    Collaborative RL networks: Pool resources with competitors to reduce costs [22]

    Digital twins: Simulate RL workflows before implementation [8].

    For Researchers:
  - Behavioral studies: Investigate consumer reluctance in emerging markets (gap [3]).
  - SME-centric models: Develop low-cost IT solutions ([2] cloud platforms).
  - Overall strength: -Strong integration of design thinking, predictive modeling, and network optimization for circular economy transitions in EVs.
  - Main gap: Lack of real-world application studies combining technical, economic, and regulatory perspectives.
  - Method diversity: Excellent mix: qualitative review [9], mathematical modeling [25], optimization and operations research [60].
  - Strategic suggestion: Future work should integrate predictive modelling + network design within policy-supported pilot projects to create scalable CE solutions for EVs.

5.2.Summary Insights on Cluster Outcomes

The main insights and results from the previous cluster analysis are as follows:

a. **Analysis of outcomes of cluster (1): -** The conclusion of the overall strength and main gaps, methods, and recommendations are summarized in Table 16, see Appendix.

b. Analysis of outcomes of cluster (2) is summarized in Table 17, see Appendix.

- Most Used Methods: MILP, multi-objective optimization, and robust optimization.
- Strongest Areas: Sustainability integration, uncertainty modelling, network optimization.
- Biggest Gaps: Real-world dynamic modelling, policy integration, human behaviour modelling.

c. Analysis of Outcomes of Cluster (3) can be summarized as follows: -

1. Methodologies Used: AHP, SEM, Balanced Scorecard, Delphi, Policy analysis, Case studies.

2. Strengths: Strong conceptual frameworks, multi-stakeholder approaches, and policy integration.

3. Gaps: Limited real-world validation, narrow regional focus, lack of predictive KPI models.

4. Strengths: Holistic KPI frameworks, regulatory integration, stakeholder participation.

5. Gaps: Lack of field validation, static models, limited geographic diversity, weak quantification.

6. Recommendations: Pilot testing, dynamic KPI evolution, global expansion, metrication, cross-sector comparison.

d. Analysis of Outcomes of Cluster (4) can be summarized as follows: -

1- Strong conceptualization, integration of Industry 4.0/5.0 with sustainability goals, innovative frameworks

2- Gaps: Lack of empirical validation, complexity of models, limited sector-specific application

3- Recommendations: Field testing, large-scale validation, dynamic updating of frameworks, cross-sector adaptability.

e. Analysis of Outcomes of Cluster (5) can be summarized in Table 18, see Appendix: -

f. Analysis of Outcomes of Cluster (6) can be summarized as in Table 19, see Appendix.

g. Analysis of Outcomes of Cluster (7) can be summarized as in Table 20, see Appendix:

6-Conclusions

The establishment of sustainable reverse logistics practices will facilitate companies in being more efficient and responsible towards their commitment to corporate social responsibility.

This study highlighted some important methodologies and performance assessments used in different aspects of reverse logistics in many industries and supply chains. Each of them had its strengths and limitations and can be used as a guide for the stakeholders and decision makers who are interested by the same scope of enhancing their organization or supply chain reverse logistics. Moreover, the paper has emphasized the importance for organizations to adopt integrated performance measurement frameworks coherent with the sustainability perspective. Future research should be directed toward filling the existing gaps which concluded in results and discussions and through the analysis of research cluster and by providing empirical evidence on sustainable practices in reverse logistics to develop a robust framework for designing sustainability reverse logistics network. In this way, researchers will be able to pave the way for better strategies that optimize not only reverse logistics operations but also contribute to the greater cause of sustainability.

7. Appendix

Table 17: Analysis of Outcomes of Cluster (2)

Aspect	Insight
Overall strength	Highly sophisticated optimization frameworks that can theoretically enhance the sustainability and efficiency of reverse supply chains.
Main gap	Lack of real-world case validations and a missing link to regulatory and consumer behaviour dynamics.
Method diversity	Strong across operations research techniques, but emerging interest in Industry 5.0 (Paper[59]) and AI-driven logistics (Paper[60]) is still nascent.
Strategic suggestion	Move toward digitally enabled, policy-driven, consumer-integrated reverse logistics networks to align with future sustainability goals and circular economy requirements.

Table 18: Analysis of outcomes of Cluster 5

Aspect	Summary
Common Methods	Optimization (MILP, MCDM, GA, robust optimization, stochastic programming)
Key Gaps	Lack of empirical case studies, too much reliance on static models, and complexity hindering adoption
Strengths	Advanced modelling techniques addressing cost, environmental, and operational objectives
Main Sectors	Electronics recycling, automotive remanufacturing, battery logistics, retail returns
Typical Objectives	Cost minimization, environmental impact reduction, network design optimization, and uncertainty handling
Strategic Recommendation	Move towards dynamic, real-time models with industrial validation and simpler implementation pathways

Table 19: Analysis of outcomes of Cluster 6

Aspect	Summary
Common Methodologies	Case studies, hybrid optimization models, simulation, legal analysis, AI modelling
Key Gaps	Limited dynamic modelling; often small sample sizes; lack of broad empirical validation
Strengths	Practical application of theory; real-world operational insights; early AI and optimization applications
Main Sectors	Electronics recycling, automotive, battery recovery, and retail returns
Typical Objectives	Optimize reverse logistics, measure sustainability KPIs, apply legal frameworks, and enhance circular economy strategies
Strategic Recommendations	Move beyond static and small-scale studies toward dynamic, scalable, and cross-sectoral case research

Table 20: Analysis of outcome of Cluster 7

Aspect	Summary
Common Methodologies	Policy analysis, conceptual modelling, comparative case studies
Key Gaps	Lack of empirical/quantitative validation; heavy focus on European or developed contexts

Aspect	Summary
Strengths	Strong theoretical underpinnings; integration of sustainability with legal obligations; multi-sector applicability
Main Sectors	Waste electrical and electronic equipment (WEEE), End-of-Life Vehicles (ELV); general reverse logistics
Typical Objectives	Develop regulatory frameworks, connect KPIs with legal requirements, and assess policy impacts
Strategic Recommendations	Expand empirical studies across more industries and regions; design flexible, adaptive legal frameworks for reverse logistics systems

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