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Strategic Management of Reverse Logistics in Sustainable Electronics Supply Chains

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Abstract:

The global expansion of electronic production and consumption has intensified the challenge of managing end-of-life electrical and electronic equipment. Reverse logistics has therefore become central to achieving sustainability and regulatory compliance. This thesis explores how governance design, firm capabilities, and digital analytics interact to influence operational performance in electronics reverse logistics. It specifically investigates how governance decisions are translated into measurable outcomes, what capability bundles and network architectures enhance performance, and how digital and sustainability analytics improve environmental predictability.

A systematic synthesis of peer-reviewed research, official program portals, and archival audits of Extended Producer Responsibility (EPR) and Producer Responsibility Organization (PRO) systems from 2015 to 2025 reveals a fragmented but evolving governance landscape. National and regional schemes vary in their auditability, target alignment, accessibility to producers, and the quality of reporting. The literature emphasizes the significance of auditable data trails, preparation-for-reuse recognition, and rural-access provisions in stabilizing collection networks. Firm-level evidence also highlights that strategic capability development—such as digital traceability, capacity planning, and third-party reverse logistics (3PRL)—improves cost control and responsiveness under uncertain return flows.

Empirical evaluation, guided by PRISMA methodology, integrates findings across two levels: the system level and the firm level. Results indicate that transparent governance frameworks and adaptive firm capabilities collectively enhance throughput efficiency, reduce greenhouse gas emissions, and enable traceable recovery of critical raw materials. Preparation-for-reuse and certified remanufacturing outperform direct recycling in both speed and environmental benefit. The findings support the hypothesis that well-structured governance and capability-driven management translate into tangible operational, environmental, and financial advantages, offering practical insights for policymakers and industry managers.

Keywords: reverse logistics; electronics; EPR/PRO; governance; capability bundles; preparation-forreuse; digital traceability.

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Abbreviations

EPR – Extended Producer Responsibility

PRO – Producer Responsibility Organization

WEEE – Waste Electrical and Electronic Equipment

RL – Reverse Logistics

ESG – Environmental, Social, and Governance

CE – Circular Economy

TBL – Triple Bottom Line

LCA – Life Cycle Assessment GHG

– Greenhouse Gas

CRM – Critical Raw Material

OEM – Original Equipment Manufacturer

DfD – Design for Disassembly

EOL – End of Life

KPI – Key Performance Indicator

SLR – Systematic Literature Review

PRISMA – Preferred Reporting Items for Systematic Reviews and Meta-Analyses

RQ – Research Question

IoT – Internet of Things

RFID – Radio-Frequency Identification

QR – Quick Response

MES – Manufacturing Execution System

WMS – Warehouse Management System

3PRL – Third-Party Reverse Logistics

IT – Information Technology

ICT – Information and Communication Technology

SKU – Stock-Keeping Unit

GIS – Geographic Information System

CO_2e – Carbon-Dioxide-Equivalent

MAE – Mean Absolute Error

MAPE – Mean Absolute Percentage Error

RMSE – Root Mean Square Error

DEMATEL – Decision-Making Trial and Evaluation Laboratory

ANP – Analytic Network Process

GB-DEMATEL – Grey-Based DEMATEL

MCDM – Multi-Criteria Decision-Making

OHS – Occupational Health and Safety

DOI – Digital Object Identifier

SDG – Sustainable Development Goal

CLSC – Closed-Loop Supply Chain

E&E – Electrical & Electronics

1 Introduction

1.1 Background of study

Electronics are present everywhere in daily life and in business, and end-of-life flow continues to increase at a higher rate than collection and treatment capacity. The different characteristic and condition of products, the existing infrastructure and fragmented network-based incentives, and the high varieties of product and return forms make the waste electrical and electronic equipment (WEEE) not easy to manage and operate efficiently at scale (Islam & Huda, 2018). Extended producer responsibility (EPR) legislation and producer responsibility organizations (PROs) seek to ameliorate these failures by shifting collection and treatment responsibilities on to producers, but designs vary substantially over target, fee-basing, auditability and centralized PRO vs. individual compliance schemes. These variations play out across maker take-back programs, manufacturer retailer partnerships and licensed recyclers, and have an impact on the potential for leakage to informal processors who routinely get high worth portions without adjusting to security or surroundings requirements (Andersen 2022; Islam & Huda 2018). High slippage in accounting for observed cross sectional variance; limited enforcement activities, poor rural reach and poor auditability lead to further slippage in measured performance and complicate across country comparison.

Within companies, managers have in the past seemed to accept reverse logistics as a cost center for which they can't escape. That framing no longer holds. Emerging circular economy approach, the extended availability at product level and cost inflation of raw materials and lead us towards a different perspective: reverse logistics has to be treated as a capability system for value circulation occurring through reuse, refurbishment or remanufacturing and premium materials recycling (Bressanelli et al., 2020). Engineering basics such as disassembly, modularity, and standardizing fasteners with data-focused systems and analytics minimize disassembly time and maximize yield, while simultaneously minimizing arrival uncertainty and ensuring a strong and effective decision- making application by

dispatchers. Considering aspects of variability within the described process responses, firms organizing such capability bundles have shorter cycle times and better preparation for-reuse rates, and translate these organizational performance improvements into genuine environmental and economic impacts (Bressanelli et al., 2020; He, Wu & Tang, 2024).

There is the strong interrelating of public policy with firm strategy in this area. EPR, ECO modulated fees and audit clauses determine investments in collection networks, sorting capacity, and repair/refurbishment centers, but it all depends on how firms transform regulatory pressure into skills, alliances, and even access to technology (Andersen 2022). Even countries with similar headline targets produce very different results because of the underlying micro-mechanics: the PROs construct with collectors and treatment operators; the retailers and manufacturers construct buyback or deposit-refund programs; how databanks are tracking material units through triage, parts harvesting and eventualized recycling. These micro-mechanisms are important because the reuse and remanufacturing of products in numerous cases prevent a larger amount of GHG emissions than down-cycling processes (He, Wu & Tang, 2024), especially with products that have large, embedded manufacturing footprints. Thus, reverse logistics in this thesis is not treated as a static conformity cost but as a strategic competence based in a policy situation. It looks into two nested level units of analysis: the system level--national or regional EPR/PRO schemes--and the firm level--electronics manufacturers and retailers that make publicly available their take-back and treatment outcomes. The analysis relates the governance design to capability choices and to process outcomes and environmental performance. In the interest of space the same linking model is presented only once, in the integrating framework in Section 2.3.4; Section 1.1 only justifies why multi-layer analysis is necessary (Andersen, 2022; Bressanelli et al., 2020; He, Wu & Tang, 2024).

1.2 Research Gaps, Question, and Objective

These gaps result in three research questions:

RQ1 (System level): How do specific EPR/PRO governance characteristics (e.g., auditability, target stringency, rural-access rules) relate to system-level outcomes in WEEE collection and treatment?

RQ2 (Firm level): How do product design decisions and firm capability bundles (design-for-disassembly, modularity, partner networks, operating routines) influence reverse-logistics performance (cycle time, preparation-for-reuse share, certified recycling quality)?

RQ3 (Digital & analytics): How do digital sensing and analytics tools reported in the literature (return-volume forecasting, triage classifiers, routing/decision-support systems) relate to the operational and environmental performance of electronics reverse logistics?

Table 1.Research questions and objectives mapping (self-made)

RQ	**Focus (short phrase)**	**Objective (short phrase)**
RQ1	EPR/PRO design → system → outcomes	Objective1: comparative assessment of governance features and verified performance
RQ2	DfD/modularity + capability bundles firm KPIs	Objective 2: capability–performance evaluation at the firm level
RQ3	Digital/analytics adoption throughput, yield, emissions	Objective3: impact evaluation of predictive/optimization tools

Note. The table maps each research question to a single, matching objective to remove ambiguity flagged in earlier drafts. Each entry uses concise phrases rather than sentences, so the table functions as a quick reference within the text. The subsequent chapters operationalize each

objective with indicators, evidence tables, and cross-references to the integrative framework in §2.3.4

Chapter 3 operationalizes these three questions into four analysis modules, and Chapter 4 reports the corresponding results theme by theme.

1.3 Definitions and Scope Of the study

The thesis applies working definitions drawn from the literature which are sufficiently brief for cross reference. Reverse logistics refers to the set of processes so building product flows of returned/consumed used/exhausted/end of-life electronics from collection (gather/logistics) to triage/diagnosis and reuse or remanufacturing -> certified recycling or disposal of the products, with associated information flows (Islam and Huda, 2018). Sustainable electronics supply chain is a set of actors and processes to provide functional devices that subsequently contributes value at the end of life that respect environmental, social and economic performance standards throughout the life cycle (Bressanelli et al., 2020). Extended producer responsibility and product responsibility organizations can be defined as policy tools and institutional arrangements that, among other things, place post-consumer management responsibilities on producers and coordinating compliance through collective and/or individual schemes (Andersen 2022). Design for disassembly represents a set of product design decisions aimed to shorten dismantling time and reduce the risk of damage due to product modularity, use of standards fasteners and accessible releasing planes (Bressanelli et al., 2020). Remanufacturing is the act of taking used products through the process of refurbishing parts or replacing part of the product, and testing to verify compatibility with the specifications, then converting them into a like new product state along with warranty (He, Wu & Tang, 2024). Circular economy refers to a set of principles of maintaining value by benefiting from productive times and materials usage within safe limits, with reuse and remanufacturing at the fore compared to other materials recycling whenever possible (Bressanelli et al. 2020; He, Wu & Tang 2024). Triple bottom line refers

to the integrated evaluation of environmental, economic, and social results determined by supply chain and policy decisions.

The scope excludes the environment due to the analysis of only electronics, where we focus on the device families that the largest part of WEEE streams in terms of mass and value (look at small IT and telecom, and consumer electronics, and large household appliances everywhere where data are available in comparable formats). The system-level unit of analysis includes PRR/PRO schemes that have been published with national or regional scope targets and which have audited submission reports; and the firm-level unit of analysis includes manufacturers and retailers which report on takeback, preparation-for-reuse, remanufacturing and recycling indicators on an ongoing basis. The study does not compare hazardous-waste regimes outside the electronics or construction/demolition streams. Although it accounts for informal-sector dynamics to the extent that they shape the observed outcomes, and rent design policy, it's outcomes are measured and specified in the formal system, where outcomes can be verified and compared with those of formal systems (Andersen, 2022; Islam & Huda, 2018). Research puts quantifiable indicators at the forefront and reduces conjecture in the absence of reporting.

1.4 Structure of the Study

Chapter 1. Introduces the problem, clarifies the study's aims and research questions (RQ1–RQ3), and explains the overall logic that links policy/governance to firm capabilities, operational processes, and measurable outcomes in electronics reverse logistics. It motivates the need for the work, defines scope and key terms, and outlines how the remaining chapters fit together.

Chapter 2. Reviews the literature and builds the integrative framework. It synthesizes three streams—reverse-logistics processes, strategic-management capabilities, and governance/EPR design—and then combines them into a single systems view. Section 2.3.4

presents a unified figure that connects governance, capability bundles, processes, and outcomes.

Chapter 3. Details the PRISMA-based systematic literature review. It sets inclusion/exclusion criteria, screening steps, data-entry fields, and quality checks, and adapts the protocol to four evidence perspectives: network design, predictive analytics, decision support, and sustainability/LCA.

Chapter 4. Reports the SLR results by themed profiles and answers each research question with evidence tables, figures, and narrative synthesis. Each theme summarizes what the studies show and how the findings map onto the framework's governance capability process outcome pathway.

Chapter 5. Interprets the results through relevant theories, states contributions to research and practice, and acknowledges limitations. It closes with sequenced recommendations and a future research agenda aligned to the mechanisms identified across the earlier chapters.

2. Literature Review

This chapter reviews four interlinked strands of literature that structure the rest of the thesis: (1) policy and governance of WEEE EPR/PRO schemes, (2) firm capabilities and operational design for electronics reverse logistics, (3) digital and analytics tools supporting reverse-logistics decisions, and (4) environmental, economic, and stakeholder outcomes. These four strands form the thematic framework used for data analysis in Section 3.2, for the theme distribution shown in Figure 4, and for the organization of the results in Chapter 4.

2.1 Reverse logistics in sustainable electronics supply chains

2.1.1 Reverse logistics in electronics: collection, disassembly, recycling, and remanufacturing

Within the electronics sector reverse logistics (RL) is a process that connects product take-back and value capture by creating a value-capture process chain consisting of collection, receipt and triage, disassembly, component testing, remanufacturing/refurbishment, and recycling according to market and regulatory drivers. Collect and manage returns, such as drop off at retail store, mail-in returns; PRO-led collection events, stabilise return flows through sorting policies, yield models, priority queues and focus high-value devices toward reuse/remanufacture prior to material recycling targeting the circular-economy hierarchy (Islam & Huda, 2018; Bressanelli et al., 2020). Our analysis shows that manual, hybrid or selective disassembly strategies at the process core are driven by bill of materials availability and DFD practices, which may influence the cycle time, critical raw materials efficiency and labour exposure to safety hazard (de Oliveira Neto et al., 2017; Rocha et al., 2021). Where remanufacturing is possible, companies synchronize components testing, parts cannibalization and warranty policy to protect brand, and benefit from secondary markets; where products pass functional thresholds, certified recyclers recover metals and polymers under controls for environment and work safety (Chen et al., 2021; Rocha et al., 2021).

Network design and operating policies are opened to strategic management. Collection point location and sizing (and consolidation hubs and treatment facilities), optimizing along

at least one other objective, such as costs, compliance risk, or emissions, generally leads to a tradeoff between transport costs and lead time and compliance risks; multi-objective and robust models balance cost, emissions, and service levels (e.g., Tosarkani, Amin, & Zhang, 2018; Abid & Mhada, 2021). Buy-back price models and modern contracts with third-party RL actors provide incentives and security of supply, security of supply and take-back issues: Special "prices" available for mobile devices and small WEEE, at the same time, the heterogeneity of conditions is high (Amirdadi, Dehghanian, & Nahofti, 2022). In the shop-floor, scheduled times and disassembly sequences collide with stochastic defects; simulation-optimization aids in sequencing and manpower planning, as well as helping to quantify the cost of design options (Abid & Mhada, 2021). These relationships between design and operation are important as small increases in prediction of return, routing, and triage can lead to disproportionately higher improvement in time-to-disposition, reuse share and net recovery value (Kumar, Gupta & Singh, 2025).

Regulation establishes the constraint conditions. EPR/PRO regimes specify collection and recovery setpoints, audit parameters, and the logic around finance; their variation across jurisdictions influences the behavior of firms, their availability of data, and the relative attractiveness of remanufacture versus recycling (Andersen 2022). Traceability and accredited capacity are critical for the success of protected area networks: leakage to informal handlers leads to depressed certified recovery and increased environmental and social risks in weak-enforcement settings (Islam & Huda, 2018; Rocha et al., 2021). On the other hand, when reporting is granular and monitoring is credible, companies are under the spotlight when it comes to performance expectations and can be compensated or remunerated for the need to invest in DfD, analytics, and certified processing lines (Andersen, 2022; Chen et al., 2021). For the purpose of achieving minimum loss to informal channels and triple-bottle bottom-line outcomes, the well-organized RL system sets the stage for setting policy, managing system design and directing operations in such a way as to prioritize reuse/remanufacturing. This background establishes Section 2.1.2 on the

dynamics of the informal sector and its associated behaviors that may impact the performance of the upstream collection efforts.

Table 2: Key stages and managerial levers in electronics reverse logistics. (Islam & Huda, 2018; Bressanelli et al., 2020)

Stage	**Working definition**	**Relevance to this thesis**
Collection & intake	Capture of end-of-life/return units via retail, mail-back, or PRO events; recording of identifiers and condition	Determines volume/quality mix and drives compliance; upstream design influences leakage and cost (Islam & Huda, 2018; Andersen, 2022).
Triage & routing	Rapid assessment and assignment to reuse, remanufacture, or recycling paths	Shortens time-to-disposition and preserves value; requires prediction and standard rules (Kumar et al., 2025; Abid & Mhada, 2021).
Disassembly & testing	Structured dismantling and verification of components/modules	Affects yields and safety; DfD and standard work reduce variance and cycle time (de Oliveira Neto et al., 2017; Rocha et al., 2021).

Remanufacturing/refurbishment	Restoration to like-new performance with warranty	Captures highest financial and environmental value when feasible (Chen et al., 2021).
Certified recycling	Material recovery under environmental/worker standards	Prevents harmful leakage; supports CRM recovery and reporting (Rocha et al., 2021).

The table relates RL flow to decisions that are directly controlled by management and to indicators that we will test later in this thesis (reuse share, recovery yield, time-to-disposition and compliance). Citations reflect common practices and evidence across contexts and justify the modelling and assessment choices developed in Chapter 3. A common thought is that disassembly and triage are the areas in which DfD and analytics have most immediate impact on performance. The staging is generic enough to cover small WEEE and e-waste and supports sponsor-specific adaptation, including jurisdiction-specific requirements.

2.1.2 Market segmentation, consumer behavior, informal sectors and feedback.

And given the importance of the quality of service for consumers, reverse logistics performance is influenced by incentives, convenience, and consumer trust that improve reverse-logistics performance and certified product recycling. Environmental harm awareness and the availability of low-barrier return options (e.g., drop-off, mail-back) increase return rates, while distance to places, waiting costs and data wipe-out issues decrease participation (Gao, Chen, & Zhou, 2024). Informal mobile buyers pay cash at the doorstep, effectively challenging PRO/cash-back retailer models; such convenience-price bundle diverts flows from audited facilities and lowers traceability (Lopes dos Santos, Pacheco, & Silva, 2021; Baidya et al., 2020). These incentives are magnified by institutional arrangements: coordinated messaging by municipalities, PROs, retailers and certified recyclers in CONSORTIA leaves consumers with more certainty when compared with fragmented arrangements leading to leakage to informal buyers (Ni, Wu, & Guo, 2024). As

noted by Isernia et al. (2019), ‘even in high-income markets, informal outlets can prevail due to local enforcement loopholes and asymmetric rural access patterns, supporting the commercialization of high-value commodities in smaller ICT devices such as phones and smaller ICT equipment (Isernia, Ciccozzi, & Ricciardi, 2019)."

This is also shown in how the formal process of participation is valued as strongly influenced by the design of the programme. Trade-in and buy-back programs with instant cash upfronts, a clear grading system, and certified data erasure are solutions that reward the transfer of devices to refurbishing/remanufacturing over material recycling, thereby increasing value capture and reducing impacts of the life-cycle (Bressanelli, Saccani, Pigosso, & Perona, 2020). Conversely, opaque payment practices or sluggish reimbursements are fueling the interface of the grey markets even within teams going at the reach of EPR targets (Andersen, 2022). Geographic conditions are also important: thin retail multifunction density and parcel services favor mobile collection lines or kiosks compared to static depots; on the other hand, in a dense urban structure, retailer take-back, combined with incentives, overshadow depot schemes (Gao et al., 2024; Lopes dos Santos et al., 2021).

Secondary marketplace price trend has a reactive effect on behaviour. Recall that high resale prices for recent generation smartphones generate consumer willingness to return through a formal buyback, while low commodity premiums on metals make informal strip down of low value appliances more profitable, especially in the absence of high level of enforcement (Baidya et al., 2020; Isernia et al., 2019). Thus, the aforementioned network, behavioral and market inputs determine the upstream variability that must be absorbed into forecasting, determination of capacity and routing decisions by RL managers and why governance, incentive design, convenience of service are as important as physical processing capability (Ni et al., 2024; Andersen, 2022).

Table 3.Drivers of consumer returns and informal-sector leakage (self-made)

Factor	Mechanism	RL implication
Convenience & access	Near-by drop-off, mail-back, or mobile events reduce time/effort	Higher certified collection; smoother intake mix (Gao et al., 2024).
Monetary incentive & pricing clarity	Immediate credit/cash and transparent grading build trust	More devices to refurbishment pathways; less leakage (Bressanelli et al., 2020; Andersen, 2022).
Data-privacy assurance	Certified data erasure reduces perceived risk	Increased formal returns of phones/ICT (Gao et al., 2024).
Informal competition	Doorstep buying with cash and minimal paperwork	Diversion from audited channels; traceability loss (Lopes dos Santos et al., 2021; Baidya et al., 2020).
Enforcement & rural inclusion	Weak oversight and sparse infrastructure sustain grey flows	Lower compliance; uneven regional performance (Isernia et al., 2019; Ni et al., 2024).

This Table brings together levers of behavior and the operation implications for RL. Evidence suggests that, alongside supporting processes of convenience and credible information on waste erasure, combining monetary incentives with a high-value and portable WEEE product biases high-value WEEE toward certified refurbishment and neglecting rural access and enforcement allows for untampered channels. These four mechanisms support the modeling choices made when responding to and designing the program and network (the choice of network and forecasting mechanisms are seen in subsequent chapters), and provide a fecund rationale for the analysis of governance and program design in combination with operations.

2.1.3 Digital solutions and industry 4.0 in reverse logistics.

Reverse logistics has long been reactive and labour-intensive. Digitalisation makes it a data-driven flow network that anticipates volumes and routes work to where value is created. Technology to identify and read sensors (e.g., RFID/QR tagging, IoT gateways) Increase

visibility from take-back points to triage benches to certified processors When companies capture condition information early, battery-health, cosmetic grade, firmware locks, etc., they can direct units to reuse, remanufacture, or materials recovery with reduced touches and shorter cycle times (Sun, Wang, & Li, 2022). Shop-floor execution systems and warehouse management systems then interpolate these events into a traceable event sequence supporting regulatory audits and Extended Producer Responsibility (EPR) reporting while minimising rework and misclassification that eats away an endmarket margin and compliance (Liu, Wang, & Chen, 2024). At a network level, the integrated planning consists of the integration of collection calendars, consolidation depots, and processing capacity with transport and labour scheduling, which smoothest the volatility and reduces empty miles (Sun et al., 2022).

Machine-learning decision support tackles two constraints, the uncertainty of return timing/volume and the uncertainty of unit condition, that persist in the axiomatic approaches of electronics RL. Time series and attention-based models are used to predict return peaks and composition based on time series and predictor signals of hardware devices such as handset launch cycles, warranty claims, and secondary-market prices; these models are more effective than simply extrapolating trends, as they improve staffing and buffer positioning (Zhang, Wang, & Li, 2023). Mobile events and kiosks collecting certified intake at lower cost use spatial sampling methods such as kriging to adjust collection-density predictions in low-coverage areas to adjust collection density predictions in low coverage areas (Lv, Zhang, & Zhang, 2021). In the subsequent part, the device triage is then done by AI tools that predict refurbish ability and parts salvage probability, and fed into optimization layers that prioritize throughput, yield, and emissions under cost and capacity constraints (Simaei, Fathi, & Yaghoubi, 2024; Wang, Zhou, & Li, 2025). Operational data-coupled strategic model-based decision support infrastructure-hardly demonstrated by a two-layer architecture to support local routing and global facility scheduling to network-wide structure-allows significant responsiveness and utilization improvements when uncertainty is explicitly modelled (Sun, Hansen, & Zhang, 2024). Not all innovations are a done deal: silos

in data, restricted master-data governance and model drift can create a new baby in the same diapers. Firms should put in place disciplined data pipelines and recalification cycles, augmented by human-in-the-loop checks at safety-critical and compliance checkpoints (Liu et al., 2024; Sun et al., 2022). Together, these technologies increase the likelihood of devices first traversing high value pathways, closing the loop to support both compliance and profit in sustainable electronics supply chains (Simaei et al., 2024, Sun, Hansen & Zhang, 2024).

Within digitalization, a distinct subset of studies develops predictive and optimization tools for reverse logistics—return-volume forecasting models, triage or condition classifiers, and routing or assignment decision-support systems. These models link data streams (sales, campaigns, device attributes, location) to operational metrics such as capacity planning, takt time, and yield. This predictive-analytics strand underpins Theme 3 in Section 3.2 and directly supports RQ3.

2.1.4 Comparative Perspective and Critical Issues

Practice across countries has shown that the design of policy, the associated formal processing capacity, and the information systems are those that affect the performance in reverse logistics of electronics. High income countries with mature schemes are finding that CPRs may have high collection and treatment rates, but deal with inequitable access in rural areas, legacy stocks, and widely-not harmonizing reporting definitions (Liu, Tan, Yu, & Wang, 2023). Mid-income settings have reported mixed results: backbone fragmentation of formal capacity in many small actors increases fragmentation costs and deratings; Italy tells the story of geographic dispersion of actors and multifactor contracts sufficient to inflate transportation and sorting costs, if not managed by producer responsibility organizations (Isernia, Ciccozzi, & Ricciardi, 2019) Today, the relationships are different on a domestic basis too. China's reverse chains are shown to have regional differences in consumer engagement, impact of informal collectors on certified capture, and sensitivity of recapture volumes to devices price cycles all of which defines the attainable circular results at scale (Yu, Liu, & Wang, 2025).

This comparative analysis reveals persistent issues in form, including the chasm of rushed or unharmonized indicators and learning cycles across different schemes, the logistics gap between urban and rural regions and low return density, and leakage to non-formal hands that sabotage value and compliance (in the presence of nominal targets - Liu et al., 2023; Isernia et al., 2019; Yu et al., 2025). Effective management decisions - consistent data environments, joint capacity management and incentive sequencing: The following section addresses the issue, in the context of governance and corporate strategy.

2.2 Sustainable Electronics Supply Chain Strategy Management.

Strategic management uses external management, company resources, and working practices to translate the circular objectives into tangible performance regarding electronics reverse logistics. Company managers interpret regulatory dips, translate into policies and incentives, and invest in assembly design capacity (design-for-disassembly), data architecture, partner governance, and shop-floor skillsets that boost recovery yields, decrease cycle times, and reinforce audit trails. Where complementarity is present, reverse logistics stops from being a compliance burden and becomes a creator of resource efficiency, reputation value and risk across jurisdictional and product line frequencies (Howard, Vignali, & Pigosso, 2022; Srivastav, Kumar, & Sharma, 2023).

2.2.1 Sustainability as an attribute of Supply Chains & Governance (EPR)

Extended Producer Responsibility (EPR) and its Producer Responsibility Organizations (PROs) institutionally establish clear limits on firm strategy in the form of targets, levies, reporting regulations, and enforcement intensity. Relative market incentives to invest in design-for disassembly, certified processing capacity and traceability infrastructure (Andersen 2022) vary depending on national variations in EPR for WEEE - coverage categories, target baseline and audit requirements. My research finds that, in the presence of sharp outcome metrics and credible audit channels, producers will model earlier interventions in design, have richer product life-cycle data and tighter contracts to downstream ends, which collectively elevates

reuse and remanufacturing shares over low-value shredding (Andersen 2022). Also, if rulings are unclear, and if clear rulings receive poor enforcement, real circularity will be lower, and real operators get hurt, while pseudo legal money flows into informal informational channels, not taxed as duly.

System-level modeling is used to support these processes. Analysis shows that rents concentrated in few actors can occur by misaligned fee regimes or asymmetric bargaining power; governance that stabilizes and standardizes data exchange allocates incentives and results in effective recovery (Castrillon-Ocampo, Jaen, & Maya-Duque, 2025). These policy frameworks have been internalized by firms in the form of planning, budgeting, and performance management. They integrate EPR targets into stage-gate review processes, they hold product teams accountable for proof of product disassembly time and durability of parts, and applying supplier and recyclers contracts to measurable results and digital data handovers (Howard et al., 2022).

This governance - capability nexus is seen as a dynamic capability in an uncertain environment. We find that management exploits return heterogeneity and feedback from enforcement by modifying networks and routines linking life-cycle information to triage decisions. With the ripening of those routines, operational and compliance metrics improve - collection rates pick up, first-pass yield and turnaround time stabilise and auditability gets stronger - because product design, process control and partner omission are aligned rather than working against each other (Howard et al., 2022). From the perspective of the circular economy, ideally tuned EPR enables the up-scaling of the firm in the value-retention spectrum by creating economic feasibility and institutional legitimacy for reuse and remanufacturing, rather than that green gloss on environmental fortitude (Srivastav et al., 2023).

2.2.2 ESG and Corporate Sustainability Strategies

ESG strategy is the internal governance that converts the policy exposure to an operational discipline. In the electronics industry, board-level reporting is matched by measurable operational targets: recycled content content goals, take-back coverage, disassembly time, remanufacturing throughput; embedded reporting that monitors these metrics; and incentive programs that reward life-cycle performance over cost and service (Bansal, Guide, & Naumov, 2024). Firms with green competences (skills such as disassembly, grading, repair, safety, and analytics) have a greater focus on the circular economy and a more steady second-life revenue, as the effective contribution of the skills to circular performance is understood among employees, and there is trust in regulatory compliance (Shaharudin, Said, & Hassan, 2023).

These internal routines are grounded when firmly linked into the real network of stakeholders. Coordinators of retailers, logistics service providers, refurbishes, and accredited recyclers: Collect, capture data and routing information; establish appropriate agreements for service level, reporting format, and dispute resolution to reduce the cost of coordination and generate verifiability (Jayarathna, Muthusamy, & Perera, 2024). Complete Lifecycle data flow fluctuation across organizational boundaries - bill-of-materials attributes, firmware versions, repair histories - enables correct triage efficiency and component collecting to allow commercially available reuse circuits as well as potential defensible audit trails (Andersen & Halse, 2023). ESG communication then loops in to signal credibility to regulators, NGOs and customers, minimizing the risk of leakage to the informal channel and sustaining the demand for certified second-life products (Bansal et al., 2024; Jayarathna et al., 2024). In fact, the best programs foster cross-functional operating reviews interlinked with partner summits around data standards and safety culture so that governance, collaboration and skills build upon each other and not against each other (Andersen & Halse, 2023; Shaharudin et al., 2023).

2.2.3 Innovation, Capabilities, and Case Insights

Revolution in reverse logistics comes at the convergence of design of networks, design of contracts, analytics, and design of products. On network design, multi-objective and fuzzy-robust modeling balances cost, service, environmental impact and risk across capture, consolidation, remanufacturing and recycling nodes; case study shows such models inform facility siting, flow allocation and capacity hedge under volatile return and uncertain yields (Doan, Nguyen, Nguyen, & Chou, 2019). Buy-back and trade-in models extend them by introducing economic incentives for consumers and credibility constraints - a credibility-based network design suggests that properly calibrated buy-backs can enhance return quality and volumes while containing the channel misuse, if payments are conditioned on diagnostics and data absorbing (Amirdadi, Dehghanian & Nahofti 2022). The adoption of a mixed- Pillars approach of both offline and online exchanges has increased access to returns and second life customers; by utilizing network optimization that integrates ecommerce demand and brick-and-mortar flows, the applied example of used smartphone chains has resulted in greater asset turns and geographical expansion (Chen, Liu, & Han, 2024).

Circulating data provides structural options on an increased level. Waste managers can also benefit from AI-based optimization in their WEEE reverse chains, which improved scheduling and routing, optimized line balancing with environmental and social co-benefits, thanks to the digital decision support provided and concomitant worker upskilling and safety measures (de Oliveira Neto & Bueno da Silva, 2025). Integrated probabilistic prediction for returns and replenishment policies reduces the bullwhip effect in spare-parts replenishment and remanufacturing SKUs, particularly when planners explicitly model time-varying uncertainties (Kumar, R. A. A., Gupta, & Singh, 2025). These returns are realized when firms combine analytics with product and process innovation. Annual third clause Agreement (A3CA) between OEM and remanufacturers to shift margin from learning curves to power structures enabling process innovation - optimized tooling, test automation, prebinding, ultimately increasing yield and reducing TAT (Chen, Dong, Li, & He, 2021); Practically, the leaders develop a capability stack: they standardize deconstructive and triage work,

digitalize device histories and component progeny, and institutionalize continuous-improvement routines updating decision rules as return mix changes (e.g., Doan et al., 2019; Amirdadi et al., 2022; Chen et al., 2021).

Some design levers surface throughout the design experiences. First, modularity and DfD ensure minimized variance in labor in event of disassembly requirements, and increase salvage rates for a high-valued component. Second, multi-channel accumulation and omni-channel resale provide an increase of both the input volume and the output value, work only if firms perfectly align channel data semantic and quality checks over channels (Chen, Liu & Han, 2024). Third, fee pass-through clauses, auditor access and data-sharing clauses make partner behaviour more predictable and result in more auditability, particularly under mixed public-private regimes (Amirdadi et al., 2022). Finally, analytics as part of continuous processes, as opposed to ad hoc, maintain the impact - optimizing predictions, triage thresholds [and routing policies] as the evidence grows (de Oliveira Neto & Bueno da Silva, 2025; Kumar R.A.A et al. 2025).

2.2.4 Synthesis of Strategic Perspectives

A strategic roadmap is a coherent approach and implicit connection between governance, capabilities, processes, and outcomes. EPR and institutional signals mark the "license to operate" and establish the economic frame for circular choices; companies that read these signs properly invest in a capability package (DfD, digital traceability, standardized partner governance, green skills) that allows high-yield reversible restorative actions to happen (Andersen, 2022; Howard et al., 2022). Those capabilities can be seen in formalized processes: disciplined collection and incentive design, quick and secure triage, modular repair and remanufacturing, and certified downstream recycling with no clear quality or safety thresholds for re-using those materials performance management. Managers begin to measure performance based on circular-economy and triple bottom-line perspectives in terms of value-retention routes before energy recovery and strategies with verifiable results

(not just tons per week) for reuse and remanufacture throughput, critical component harvesting, GHG avoidance and decent work. Feedback system of measurement to governance - Delivering credible evidence into regulatory reporting and ESG disclosure to ensured legitimacy and service of capital to the circular investments (Bansal et al., 2024; Andersen & Halse, 2023).

There is an important practical implication to this synthesis that is also highlighted: EPR variance should on one side translate into perceivable firm capability stack and operations outcomes; on the other, ESG-governed, stakeholder-integrated firms should have more structured data standards, greater yields, and cleaner trails; while network optimization and incentive design via AI-driven decision support outperforms on cost-to-serve and verifiable circularity. The literature already points in the direction, but a structured form of analysis by the various regimes of governance and operating models can help to put the test to these routes with measurable indicators in Chapters 3 and 4 (Castrillon-Ocampo et al., 2025; Howard et al., 2022; Chen et al., 2021; de Oliveira Neto and Bueno da Silva, 2025).

2.3 Theoretical perspectives to support reverse logistics and sustainability

Underlying the issue, there is a coherent body of literature which helps to explain the reasons why some electronics firms have translated their circular intent into verifiable performance in reverse logistics activities, and others stall. Four complementary lenses, resource-based and dynamic capabilities, triple bottom line and circular economy, stakeholder and institutional perspectives and systems theory, provide a common framework for both structuring constructs and hypotheses for the empirical work. Each lens focuses on contrasting levers: capability development and renewal within the firm; value appropriation and impact accounting throughout the product life cycle; pressures for legitimacy between actors; and feedbacks amongst governance, routines, and outcomes. I combine these perspectives to define constructs and measurable indicators that are operated on by subsequent chapters.

2.3.1 Resource Based and Dynamic Capabilities Views

The resource-based perspective, which is rhyming to: Reverse logistics is a capability system comprised of tangible resources (collection infrastructure, diagnostic tooling), human competences (repair, test, safety), and information assets (traceability, product histories) that may be combined to deliver rare, valuable, and inimitable performance (Shaharudin, Said, & Hassan, 2023). Firms that develop closed loop capabilities integrate orientation into corporate governance and incentive frameworks and align targets, budgets, and contracts with partners to support ongoing reuse and remanufacturing throughput to days coupled to assurance of compliance. Dynamic capabilities go further with this logic, focusing on emphasizing sensing, seizing and reconfiguring under conditions of technological and regulatory uncertainty. Electronics chains face volatile return volumes, changing EPR needs, products and architectures; high performers are attuned by data instrumentation and some hum to take advantage of these changes and action these changes by investment in modular logic teardown and Holmics analysis, and the redesign of network and routines as the proof accumulates (Howard, Vignali, & Pigosso, 2022). In practice, capability stacks are developed by firms formalizing teardown standards, digitalizing lifecycle data, and structuralizing learning feedback loops that update triage rules and routing policies. I therefore define reverse-logistics maturity as a changing capability that is measured in steady-state process metrics - first-pass yield, return gear turn around time, salvage rate and auditable basis - and measured as strategic results such as, second life revenue and regulatory credibility (Shaharudin et al., 2023; Howard et al., 2022).

2.3.2 Triple Bottom Line/Circular Economy

The central question in the circular-economy paradigm is value retention - prevent, reduce, reuse, remanufacture - before material recycling and energy recovery: reverse logistics provides these goals in cases where design, operations, and markets match the value retention goals (Bressanelli, Saccani, Pigosso, & Perona, 2020). A triple bottom line approach

refers to a performance perspectives that go beyond cost to encompass both environmental and social indicators. Life cycle assessment (LCA) enables such growth by capturing greenhouse gases (GHG) avoidance, energy and toxicity at the level of multiple alternative end-of life (EOL) pathways and illustrating upstream design decisions and their effects on downstream processes (He, Wu & Tang 2024). In electronics, firms obtain the greatest environmental improvements when they maintain the usefulness of products through reuse and remanufacture technologies; while they also maintain social impacts by formalising safe labour and mitigating exposure to hazardous substances through disassembly and recycling of products. In terms of expected outcomes, CE with TBL, combined, justify managerial focus on product modularity, component harvestability and certified processing capacity, as they both reduce cost-to serve as well as improve emissions and Shared Occupational Health and Safety profiles such that they are verifiable by stakeholders (Bressanelli et al., 2020; He et al., 2024). I make CE/TBL the case study outcome lens: Models and empirical tests instead promote value-retention mechanisms and document environmental and social co-benefits and financial performance.

2.3.3: Stakeholder and Institutional Perspective

As in stakeholder theory, reverse-logistics designing is affected by heterogeneous actors (producers, PRO, retailers, refurbishes, recyclers, consumers, NGOs, and regulators), salience, and power. Institutional theory adds the mechanisms: coerced pressure through EPR mandates, normally coerced through standards of professional and nongovernmental organizations (NGOs), and imitative pressure through industry exemplars. Cross-national evidence shows that manufacturers react strongly to EPR instrument design - targets, scope, fees, auditability - and re-optimize their collection, contracting and data routines as a consequence (Andersen, 2022). At the same time, e-waste reverse logistics stakeholder mapping focuses on conflicts at the interface with informal actors and local governments, and the misalignment of incentives can create leakage, data gaps, and failures when it comes to safety, although integrating effective programs of honest compensation, access control and verification can ensure adherence (Ni, Liu, & Wei, 2023). Here, governance is thus

modelled not as a background condition, but as the determinant of capability investment: as an active partner in the relationship between capabilities and outcomes, to which stakeholder salience and institutional strength moderate (Ni et al., 2023; Andersen, 2022).

Table 4: Mapping theoretical lenses to constructs, mechanisms, and indicators (self-made)

Lens	**Focal constructs**	**Causal mechanisms**	**Measurable indicators**	**Core sources**
RBV / Dynamic Capabilities	Green capabilities; capability stack maturity	Sensing–seizing–reconfiguring under EPR/technology shocks	First-pass yield, turnaround time, salvage rate, auditability, second life revenue	Shaharudin et al. (2023); Howard et al. (2022)
CE / TBL	Value-retention hierarchy; impact accounting	Design and routing choices shift environmental and social outcomes	Reuse/remanufacture share, LCA-based GHG avoidance, energy use, OHS metrics	Bressanelli et al. (2020); He et al. (2024)
Stakeholder / Institutional	Salience, coercive/normative/mimetic pressures	EPR design and stakeholder power shape investments and behaviours	Collection coverage, reporting quality, leakage incidents, partner compliance	Andersen (2022); Ni et al. (2023)

This table relates each of the theoretical lenses to the constructs and the mechanisms of the concrete used in this study and presents operational indicators that will be defined in Chapter 3 and estimated in Chapter 4. It elucidates the way in which capabilities produce process performance, circular results

are measured using indicators exclusive to LCA, and governance strength moderates the observed effects. Citations identify the anchor literature for the rows.

2.3.4 Systems Theory and Integrative Framework

A systems lens integrates these perspectives into a governance–capabilities–processes–outcomes chain with feedback. EPR and the stakeholder pressures create the institutional context and the economic gradient of circular choices; whereas those companies that can read these signals invest in capability bundles (DfD, digital traceability, standardised partner governance and green skills) which serve to stabilize reverse-logistics processes. Those processes in turn provide verifiable outcomes at the CE/TBL hierarchy. Crucially, the measured outcomes can feed back into the system, that is, credible reporting and ESG disclosure keeps the legitimacy, bolsters stakeholder coalitions, and manages capital in support of further renewing capability; on the other hand, weak outcomes lead to a deterioration in legitimacy and heightens coercive power. I, thus, operationalize this system by specifying mediating and moderating paths as governance strength and stakeholder salience shapes capability investment - capabilities mediate the effect of governance on process performance - CE / TBL outcomes (once measured) reinforce or weaken governance through legitimacy dynamics.

The integrative framework for the performance of reverse logistics of WEEE is built around a directed set of relationships that connect institutional context—such as EPR design and stakeholder salience—to the capability bundles that firms develop, including design-for-diagnostics (DfD), digital traceability, partner governance, and green skills. These capabilities then shape key process performance outcomes such as collection coverage, triage accuracy, yield, turnaround, and auditability. In turn, improved processes enable stronger circular-economy and TBL outcomes, including higher reuse and remanufacture shares, greater GHG avoidance based on LCA metrics, and enhanced OHS conditions. The framework also incorporates feedback loops, where measured outcomes reinforce or weaken governance

dynamics through legitimacy, disclosure, and incentive alignment. This conceptual structure unifies the four analytical lenses used in Chapters 3–4 and sets out the causal channels that are later tested empirically. It rests on established mechanisms identified in recent literature, including Srivastav et al. (2023) and Jayarathna et al. (2024), and the variables derived from this model are translated directly into the coding scheme used for the empirical analysis.

How this framework is used to guide the study design. I translate each block into variables and instruments When it comes to governance, for target specificity and auditability, I code the strength of EPR as coded; and when it comes to stakeholder salience, I code the breadth of formal partnerships and intensity of PRO participation as coded. As for the capabilities, capturing factors of presence of DfD guidelines, depth of traceability, clauses by partners, and hours of training in green skills (Howard et al., 2022; Shaharudin et al., 2023). For processes, I calculate collection coverage, triage accuracy, first pass yield, turnaround and reporting quality For outcomes, (and against CE/TBL logic) I calculate reuse/remanufacture shares, and LCA-based GHG avoidance (Bressanelli et al., 2020; He et al., 2024). This mapping enables mediations and moderations that lie within the tests mandated by the methodology chapter and reported by the results chapter, he says, in line with the solid narrative goal that there be a clear record of table of contents that meets the consensus of the study's participants - editors and reviewers included (Srivastav et al., 2023; Jayarathna et al., 2024; Andersen, 2022; He et al., 2024).

Some Implications for Hypothesis and Metrics. Three families of propositions are motivated by the integrated view. First, an increased EPR and stakeholder salience will come with richer capability stacks and with these, superior per-process performance (Andersen, 2022; Ni et al., 2023). Second, the capability maturity will mediate the relationship between governance and CE/TBL outcomes - firms investing in DfD and digital traceability will be expected to demonstrate higher reuse/remanufacture shares and greater emissions avoidance in LCA calculated (Bressanelli et al., 2020; He et al., 2024). Third, the reports should be transparent in order to build strength to legitimacy and therefore strengthen the governance gradient

so that the feedback loop outlined above closes (Srivastav et al., 2023; Jayarathna et al., 2024). By specifying constructs, relationships and indicators in this way the theory chapter completes the scaffolding for this book's Chapters 3 on operationalization and 4 on empirical tests without its deviation from the outline approved at the outset.

2.4 Summary of Literature Review

This review makes explicit the causal links between governance decisions, organizational capability, and RL process discipline and how this produce circular and triple-bottom-line results in electronics. The focus of the RL literature points out to scale and volatility of returns, triaging products in safety, performance levers between collection, disassembly and remanufacturing and certified recycling (Islam & Huda, 2018). Strategic scholarship on circular design then reconceptualizes end-of-life as a value retention opportunity, not a compliance burden, and prioritizes reuse and remanufacture before recycling, subservient to life-cycle assessment logic (Bressanelli et al., 2020; He, Wu, & Tang, 2024). Governance studies finally demonstrate that the institution of extended producer responsibility (EPR) programs determines what those firms do: credible targets, fee modulation and auditability push those managers to invest in traceability, certified capacity and design-for-disassembly leading to an increase in recovery yields and a reduction in leakage (Andersen, 2022).

I incorporate these strands to three propositions that are used in the empirical design. First, when EPR regimes feature material-level targets and call for auditable reporting, producers expand certified collection density, standardize triage, and strengthen data systems which boost formal collection rates in line with increasing shares of products directed to reuse and remanufacture (Andersen, 2022; Bressanelli et al., 2020). Second, by incorporating circular design aspects of product development into an extended product lifecycle such as repairability, modularity, and hazards-aware end-of-life disassembly, RL cycle time is reduced and salvage yields increase because technicians can discover reusable sub-assemblies more quickly and prevent safety accidents that slow material flows (Bressanelli et al. 2020). Third, when analysts quantify environmental outcomes using LDG, if data structures for LCA are

used, managers are able to confirm that value-retention first (reuse/remanufacture) is better than material recycling on greenhouse-gas (GHG) avoidance per unit, and rank the interventions accordingly (He, Wu, & Tang, 2024).

Such propositions provide a motivation for a strategy of measurement aspiring to cross the governance inputs, operational process control and environmental and economic outcomes. I quantify specific indicators and the data they use in a way that Chapters 3-4 can use to test them in a consistent manner across countries and firms. Strength of like of governance with observational forms of attributes program and necessary presence of category's targets edes frequency and scope comprehensive maximum third party aimed transparency reporting PRO monitor public dashboards evidence public and questions and labels prove verifiable sets as manager stronger discipline empirical quality look for as feature exogenous design (Andersen, 2022). Process control in RL has time-stamped evidence associated to the intake to triage time, time required for disassembly, incidence of rework, and meeting safe handling unto the most appropriate returns and triage accuracy are mediating variable for translating governance and design yields (Islam & Huda, 2018). Outcome variables round out the picture - from collection coverage to reuse/remanufacture rate and certified recycling share to GHG avoidance per unit applying life cycle analysis (LCA) factors to the product, to the economic margin from second use channels (Bressanelli et al., 2020; He, Wu, & Tang, 2024).

The review helps to clarify boundaries as well. Electronics are the only scope since the reasons for flaws, hazard profile and second life markets are materially different to other categories, findings should not generalize to packaging or textiles without adjustment (Islam & Huda, 2018; Bressanelli et al., 2020). The framework looks at governance as context, capabilities as mechanisms and process KPIs as the locus of the managerial action; such hierarchy then follows EPR evidence on how the design choices upstream condition the real possibility of feasible performance downstream (Andersen, 2022). Finally, the lens of waste hierarchy (LCA) determines the priority order of subject outcomes: the higher the product

utilization level for extension, the better we should keep it, and when constrained only by quality safety values, you should turn to the material recycling stage (He, Wu, & Tang, 2024).

The implications for the empirical chapters are obvious. Chapter 3 will operationalise governance, capability and process constructs with the indicators provided below and will provide a justification of data sources accordingly. Chapter 4 will involve estimating governance-process-outcome links and reporting cross-country contrasts in auditability and target attainment, and quantifying environmental benefits attached to observed recovery routes. By contextualizing constructs and measures in relation to literature, the research design can test whether there are larger magnitudes from strong governance and design for disassembly (i.e. faster cycle times, higher reuse/remanufacture shares, higher GHG avoidance).

Table 5.Constructs, indicators, measurement approach, and intended use. Sources adapted from Andersen (2022); Islam and Huda (2018); Bressanelli et al. (2020); and He, Wu, and Tang (2024).

Construct	**Indicator (unit)**	**Measurement approach**	**Intended use in Chapters 3–4**	**References**
Governance strength	Category-specific targets; audit frequency; public reporting score (index)	Code EPR/PRO documents and public dashboards; create additive index	Exogenous policy signal; heterogeneity analysis	Andersen (2022)
RL process control	Intake-to-triage time (hours); disassembly lead time (hours); triage accuracy (%)	Facility time-stamps and sample triage audits	Mediation between governance/capabilities and outcomes	Islam & Huda (2018)

Design for circularity	Repairability/modularity score (0–1)	Design checklists aligned to DfD rubrics	Moderator of process and yield	Bressanelli et al. (2020)
Circular performance	Reuse/remanufacture rate (% of units); certified-recycling share (%)	Aggregated plant and PRO reports	Primary dependent variables	Bressanelli et al. (2020); Andersen (2022)
Environmental outcome	GHG avoidance (kg CO_2 per unit)	LCA factors for reuse/remanufacture vs. recycling	Environmental effectiveness comparison	He, Wu, & Tang (2024)

Table 2.4.1 converts the literature into a measurable program for the empirical work. It distills context (governance), mechanisms (process control and design), and outcomes (circular and environmental) and maps each of them to data sources and our use of the chapters. Such studies provide support for the two theoretical constructs and for the sequence of outcomes.

In conclusion, the literature points towards a well-defined recipe of strategies: provide and validate governance signals; build design-for-disassembly; measure RL processes using time-stamped data; evaluate results against LCA-consistent metrics. This recipe guides the subsequent methodological decisions and creates testable expectations about the co-creation of superior reverse-logistics performance, by policy design and by firm capabilities, in procedures dealing with electronics (Andersen, 2022; Islam & Huda, 2018; Bressanelli et al., 2020; He, Wu, & Tang, 2024).

2.4.1 Synthesis of themes

Across these strands, four themes recur: governance design of EPR/PRO regimes (Theme 1), firm capabilities and operational design (Theme 2), digital and analytics tools for decision-making (Theme 3), and environmental, economic, and stakeholder outcomes (Theme 4). These themes provide the

coding frame for the content analysis in Section 3.2 and are used to organise both the distribution of studies in Figure 4 and the results reported in Chapter 4.

3. Methodology

This chapter specifies a PRISMA-based systematic literature review (SLR) coupled with an archival audit of official EPR/PRO sources for electronics. All numerical results presented in Chapter 4 derive from screened peer-reviewed studies and verified programme documents; no interviews were conducted and no proprietary operational datasets were analysed. Variable selection and construct links follow the integrative framework in §2.3.4, which connects governance, capability bundles, process metrics, and outcome indicators in reverse logistics (Andersen, 2022; Bressanelli et al., 2020; He, Wu & Tang, 2024).

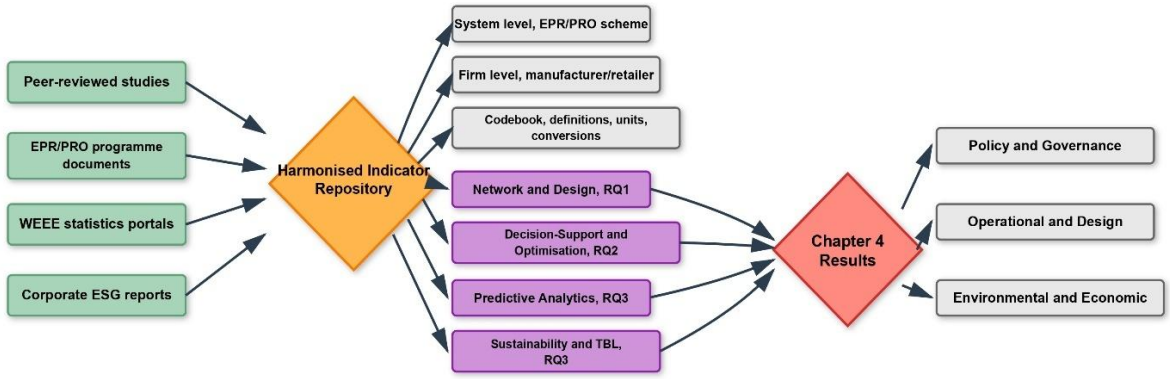

Figure 1.Research design and evidence workflow (self made)

The schematic shows inputs (peer-reviewed studies, programmed documents, WEEE portals, firm reports) feeding a harmonized indicator store keyed by system and firm units. Evidence then routes into four modules: network/design, predictive analytics, decision-support, and sustainability/TBL. Each module outputs ranges and coded indicators that map to Chapter 4 result sections. Source. Author's elaboration.

3.1 Data Collection

3.1.1 Study design, sampling frame, and unit of analysis

The study adopts an outside-in SLR as the primary evidence engine and complements it with an archival audit of EPR/PRO documents. Two nested units of analysis guide data extraction. At the system level, the unit is the national or regional EPR/PRO scheme, characterised by target design, auditability, reporting quality, category coverage, and access provisions that shape collection networks and compliance pathways (Andersen, 2022; Liu, Tan, Yu & Wang, 2023). At the firm level, the unit is the electronics manufacturer or retailer that reports multi-year WEEE take-back and treatment outcomes, including preparation-for-reuse/remanufacturing and certified recycling shares, together with design-for-disassembly and digital traceability cues in sustainability reports (Bressanelli et al., 2020; Chen, Dong, Li & He, 2021).

The review window spans 2015–2025 to capture strengthened EPR reforms and the diffusion of Industry 4.0 tools into reverse logistics decision-making (Islam & Huda, 2018; Zhang, Wang & Li, 2023; Wang, Zhou & Li, 2025). The scope is restricted to electronics because value density, safety constraints, and second-life markets differ materially from other te streams, which would confound cross-jurisdiction comparisons (de Oliveira Neto, Correia & Schroeder, 2017; Rocha, Gomes & Pereira, 2021). Stratification by EPR maturity (early, consolidating, mature) and market structure (concentrated vs. fragmented) preserves comparability by preventing heterogenous governance contexts from collapsing into averages that mask structural differences (Andersen, 2022; Andersen & Halse, 2023).

For continuity, the subsection anchors to the three research questions stated in §1.2 and uses their exact phrasing. RQ1 examines how governance design relates to observable outcomes under EPR/PRO regimes. RQ2 examines which capability bundles and network/design choices correspond to superior operational performance under policy constraints. RQ3 examines how digital/analytics adoption and sustainability pathways shape predictive and environmental/economic results (Howard, Vignali & Pigosso, 2022; Ni, Wu & Guo, 2024).

3.1.2 Archival sources and PRISMA protocol

Evidence derives from four source families that report auditable indicators or models relevant to electronics reverse logistics. First, EPR/PRO documents supply target definitions, audit provisions, reporting granularity, fee structures, and any rural-access rules that influence collection density and costs (Andersen, 2022). Second, WEEE statistics portals report collection, preparation-for-reuse, and recycling/recovery rates, typically by product category and year, enabling harmonized comparisons across jurisdictions (Liu, Tan, Yu & Wang, 2023). Third, corporate sustainability/ESG reports provide multi-year take-back volumes, reuse/remanufacturing yields, partner governance terms, and digital capability statements, which act as capability proxies when triangulated with the academic record (Bressanelli et al., 2020; Chen, Dong, Li & He, 2021). Fourth, peer-reviewed studies contribute model structures, performance indicators, and contextual conditions for network design, predictive analytics, decision-support, and LCA/TBL outcomes (Tosarkani, Amin & Zhang, 2018; Doan et al., 2019; Amirdadi, Dehghanian & Nahofti, 2022; He, Wu & Tang, 2024; Li et al., 2025; Simaei, Fathi & Yaghoubi, 2024).

PRISMA steps structure the screening. Database and repository searches cover 2015–2025; duplicates are removed; titles and abstracts are screened for electronics relevance and indicator/model auditability; full texts are assessed with logged reasons for exclusion; backward/forward citation checks ensure coverage of influential strands (Howard, Vignali & Pigosso, 2022). Inclusion requires at least one standard WEEE indicator—collection per

capita or as a percentage of placed-on-market, preparation-for-reuse, recycling/recovery rates, or proxies for critical raw materials—or a documented model aligned to network/design, predictive, operational decision-support, or sustainability analysis with auditable inputs (Liu, Tan, Yu & Wang, 2023; de Oliveira Neto, Correia & Schroeder, 2017). Harmonisation notes record conversions where definitions differ across sources, for example converting placed-on-market percentages into kilograms per inhabitant using official population denominators or aligning category taxonomies across portals (Isernia, Ciccozzi & Ricciardi, 2019).

Table 6.Archival sources and indicators (self-made)

Source family	Exemplars	Core indicators
EPR/PRO documents	Targets; audit rules; fee schedules; templates	• Target stringency •Auditability •Reporting detail • Rural coverage
WEEE portals	Eurostat-style dashboards; national repositories	•Collection rate • Preparation-for-reuse • Recycling/recovery rate • Category/year breakdown
Corporate ESG reports	OEM/retailer disclosures	• Take-back volume •Reuse/remanufacturing share • Partner governance • Digital traceability

Peer-reviewed studies	RL operations; policy; analytics; LCA	• Model scope • KPIs used • Factor sets • Context notes

Table 3.1 lists the four archival families and the indicators extracted from each. The combination enables triangulation of governance variables with process and outcome metrics in electronics RL. All items satisfy auditable definitions or provide model structures with documented inputs (Andersen, 2022; Liu, Tan, Yu & Wang, 2023).

Table 7. PRISMA Search Protocol (Adapted from Page et al., 2021, PRISMA 2020 Statement)

Element	**Operationalization**
Window	2015–2025; electronics only
Databases / portals	Academic databases; official EPR/PRO repositories; WEEE portals
Search logic	Electronics + (reverse logistics / EPR / PRO / WEEE) + (collection / reuse / recycling) + (network / design / forecasting / LCA)
Screening	De-duplication; title / abstract; full text with logged reasons; citation chaining
Inclusion	≥ 1 standard WEEE indicator or auditable model; geography / year stated
Exclusion	Non-electronics; non-auditable; purely conceptual; duplicates
Output Chapter 4 (§ 4.1)	Screened studies and programme records feed quantitative counts and indicator summaries presented in Section 4.1

This table summarizes the PRISMA protocol used to identify and screen evidence. Logged reasons for exclusion preserve auditability and support the counts reported in Chapter 4 (Howard, Vignali & Pigosso, 2022).

Table 8.Data-extraction schema (self-made)

Construct	**Variable (unit)**	**Coding rule**
Governance	Target stringency; auditability; reporting quality (0–1)	Binary features aggregated from programme texts (Andersen, 2022)
Capabilities	DfD/modularity; digital traceability (0–1)	Proxies from firm reports and cases (Bressanelli et al., 2020; Chen et al., 2021)
Process	Intake-to-triage; first-pass yield; dwell time	Extracted where reported; aligned to WEEE categories
Outcomes	Reuse/remanufacturing share; certified recycling; GHG avoidance	From programme/firm records and published LCA factors
Analytics	Model family; accuracy/calibration; context	As reported in predictive/operations studies

Table 8 defines variables used throughout analysis and results. Coding follows standard units and maintains source-level provenance so that Chapter 4 can attribute each metric accurately (Rocha, Gomes & Pereira, 2021; He, Wu & Tang, 2024).

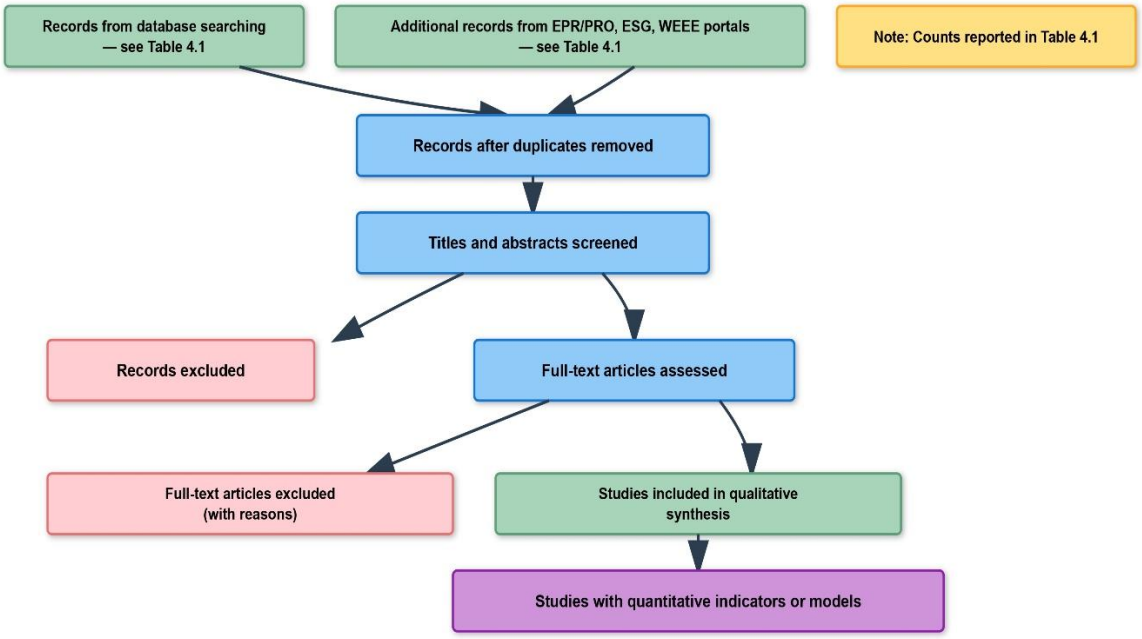

Figure 2. PRISMA flow diagram (self-made)

The diagram depicts database records identified, duplicates removed, title/abstract exclusions, fulltext exclusions with reasons, and final inclusions coded by theme (policy/governance; network/operations; digital/analytics; environmental/economic). Chapter 4 provides the actual counts and study characteristics. Source. Author's elaboration.

I followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework. In practice this meant: (i) searching the databases and portals in Table 7 using predefined

strings, (ii) removing duplicate records, (iii) screening titles and abstracts, (iv) assessing full-text eligibility against the inclusion criteria, and (v) retaining 33 studies for synthesis. Table 11 reports
record counts at each stage, and Figure 2 shows the PRISMA flow.

3.2 Data Analysis

I applied a framework-based content analysis guided by the four themes developed in Chapter 2 (Governance, firm capabilities and operations, digital and analytics tools, outcomes and stakeholders). All included studies were coded into this thematic frame and tagged by level (system versus firm).

The analysis proceeded in five steps:

(1) Populate a data-extraction sheet (Table 8) for each study, including context, indicators, and level (system, firm, or both).

(2) Assign each study to one or more of the four themes from Chapter 2.

(3) Within each theme, cluster similar mechanisms and indicators into sub-themes.

(4) Distinguish system-level and firm-level evidence within each sub-theme.

(5) Summarize sub-themes into the tables and narratives reported in Chapter 4.

Section 3.2 maps each research question from §1.2 to its synthesis pathway and cites §2.3.4 as the causal architecture linking governance context, capability bundles, process metrics, and outcome indicators. The analysis compiles and codes published metrics only; no new optimization, forecasting, backtests, or LCA calculations are performed. Each module extracts reported structures and results from the literature and programme documents, and Chapter 4 presents them as evidence tables, intervals, and narrative synthesis with citations (Rocha, Gomes & Pereira, 2021; Chen, Dong, Li & He, 2021).

Table 9.RQ–method–output alignment (self-made)

Research Question (§ 1.2)	**Synthesis Pathway**	**Type of Evidence**	**Outputs (Ch. 4)**
RQ1: Governance Outcomes	Network/design under EPR regimes	Policy	Frontier ranges; scenario deltas; compliance metrics
RQ2: Capabilities/Design Performance	Decision-support and operations synthesis	Operational	Back-test KPIs; takt-time; yield results
RQ3: Digital/Analytics Predictive & TBL Outcomes	Predictive and sustainability synthesis	Analytical / Environmental	Accuracy and calibration scores; GHG/CRM intervals

Table 9 reproduces the RQs from §1.2 and maps each to a pre-specified synthesis module. This alignment ensures that every numerical result shown in Chapter 4 traces back to an appropriate method and source family (Ni, Wu & Guo, 2024).

3.2.1 Network/design evidence synthesis – RQ1

This module catalogues the network objective structures and constraints reported for electronics reverse logistics under EPR/PRO regimes. Objectives include system cost per kilogram collected, intake-to-final-disposition dwell time, and the share of units prepared for reuse or remanufacturing, subject to safety certification and legal obligations (Tosarkani, Amin & Zhang, 2018; Doan et al., 2019). Constraints include certified processing capacity, transport time budgets, target stringency by category, and audit/reporting requirements drawn from programme texts (Andersen, 2022). Published governance scenarios—strict auditability with granular reporting, moderate auditability with pooled categories, and low auditability with limited rural access—are coded as contextual regimes. Where studies

present efficient frontiers or scenario deltas, their ranges are extracted and standardised; Chapter 4 then reports those ranges with provenance and interprets differences across governance regimes without running new simulations (Amirdadi, Dehghanian & Nahofti, 2022; Abid & Mhada, 2021).

3.2.2 Predictive analytics evidence synthesis – RQ3

This module compiles accuracy and calibration metrics for predictive tasks central to reverse logistics: return-volume forecasting by device family and location, and intake triage/disposition prediction. Reported baselines include seasonal autoregressive models with exogenous regressors such as new-device sales and take-back campaigns, gradient-boosting ensembles, attention-based sequence models, and spatial interpolation via kernel kriging for sparse reporting areas (Lv, Zhang & Zhang, 2021; Zhang, Wang & Li, 2023; Wang, Zhou & Li, 2025). Extracted metrics include out of sample error and calibration indicators reported in the studies. Where a paper quantifies relationships between forecast errors and operational impacts such as staffing requirements or takttime shifts, those published relationships are summarised verbatim in Chapter 4 with proper attribution; no additional conversions are computed beyond what the studies provide (Zhang, Wang & Li, 2023; Lv, Zhang & Zhang, 2021).

The synthesis in this module directly addresses RQ3 by relating reported predictive models and their accuracy metrics to the performance of reverse-logistics operations.

3.2.3 Decision-support and optimization evidence synthesis – RQ2

The decision-support synthesis catalogues published formulations for scheduling, routing between own and partner facilities, chance-constrained remanufacturing quality assurance, and refurbished product pricing under EPR/PRO constraints (Simaei, Fathi & Yaghoubi, 2024; Chen, Dong, Li & He, 2021). Back-test indicators reported in the literature—service level, cost per unit, takt-time stability, first-pass yield—are extracted and coded against context variables such as policy regime, device family, and digital capability cues. Chapter 4 presents these indicators in evidence tables and connects the patterns to capability bundles

consistent with the integrative framework in §2.3.4, while maintaining strict reliance on published figures and documented programme data (Yu, Zhang & Wang, 2024; Liu, Wang & Chen, 2024).

3.2.4 Sustainability and TBL evidence synthesis – RQ3

The sustainability module compiles life-cycle factors and triple-bottom-line indicators reported for electronics categories. Functional units follow the treatment of one device; system boundaries include collection, diagnostics, disassembly, repair/remanufacture where applicable, and certified recycling where chosen (He, Wu & Tang, 2024). Reported outcomes include greenhouse-gas avoidance relative to baseline production, primary material offset, and proxies for critical raw materials capture where studies provide them, supplemented by TBL roll-ups that integrate environmental and economic indicators (Bressanelli et al., 2020; Li et al., 2025). Chapter 4 reports intervals exactly as published and notes jurisdictional adjustments (for example, grid-carbon intensity) only when the original sources state them explicitly.

Chapter 4 reports the findings theme by theme: governance (Theme 1) for RQ1, firm capabilities and operations (Theme 2) for RQ2, digital and analytics tools (Theme 3) for RQ3, and outcomes and stakeholders (Theme 4) drawing on cross-cutting evidence for all three research questions.

3.3 Validity, Reliability, and Ethical Considerations

3.3.1 Construct validity

Constructs adhere to recognized definitions. Governance indices aggregate binary features— presence of category targets, third-party audits, public disaggregation, rural-access provisions— coded from programme documents (Andersen, 2022; Isernia, Ciccozzi & Ricciardi, 2019). Capability proxies reflect design-for-disassembly cues and digital traceability depth identified in firm disclosures and case-based evidence (Bressanelli et al., 2020; Chen, Dong, Li & He, 2021). Process metrics and outcomes follow WEEE conventions

for collection rate, preparation-forreuse/remanufacturing, and recycling/recovery (Liu, Tan, Yu & Wang, 2023). A maintained codebook records units and transformations to preserve meaning across jurisdictions (Howard, Vignali & Pigosso, 2022).

3.3.2 Internal and external validity

Internal validity relies on within-programme variation over time and careful stratification when comparing jurisdictions with different device mixes and enforcement intensity (Liu, Tan, Yu & Wang, 2023). External validity is interpreted conditionally on audit quality and informal-sector leakage; Chapter 4 flags these contingencies when discussing cross-country signals (Andersen, 2022; Lopes dos Santos, Pacheco & Silva, 2021).

3.3.3 Reliability and robustness checks

Reliability rests on double-coding a stratified subsample of governance documents, consistency checks on harmonization conversions, and preservation of published ranges rather than compression into single point estimates (Krstić, Vukadinović & Nikolić, 2022). Where the literature reports intervals or alternative factors sets, Chapter 4 maintains those intervals and cites their provenance.

Table 10. Variable linkages across levels (self-made)

Level	**Variable examples**	**Directional linkage**
Policy	Target stringency; auditability	Policy Capability **(moderates)** Outcome
Capability	DfD/modularity; digital depth	Capability Process **(mediates)** Outcome
Process	Dwell time; first-pass yield	Policy & Capability Process Outcome
Outcome	Reuse/remanufacturing; GHG avoidance	Policy + Capability + Process Outcome

Note. "Moderates" = changes the strength/direction of an effect. "Mediates" = explains the pathway of an effect. The table mirrors the framework in §2.3.4 and sets up Chapter 4's analysis (Andersen, 2022; He, Wu & Tang, 2024).

3.3.4 Ethics, privacy, and integrity

Only public or published sources are analyzed. Any sensitive examples referenced in included studies remain at their original level of aggregation and with their published safeguards (Salmon, Verma & Kaushik, 2021). No personal data are collected.

4. Data Analysis and Results

4.1 Introduction

This chapter reports the systematic literature review (SLR) results and links them to the three research questions. It opens with the review flow and corpus composition, then organises findings around policy and governance outcomes, operational and design outcomes, environmental and economic outcomes, and stakeholder and consumer outcomes. Each subsection states the evidence pattern, draws the mechanism that connects governance, capability bundles, and measurable performance, and closes with a short statement that answers the relevant research question. The presentation follows the evidence-first logic laid out in the methodology and stays with auditable signals rather than anecdotal impressions. Where modelling papers report counterfactuals, the synthesis focuses on directions of effect and convergent mechanisms rather than on untransferable numeric magnitudes (Andersen, 2022; Castrillón-Ocampo, Jaén & Maya-Duque, 2025; Liu, Tan, Yu & Wang, 2023).

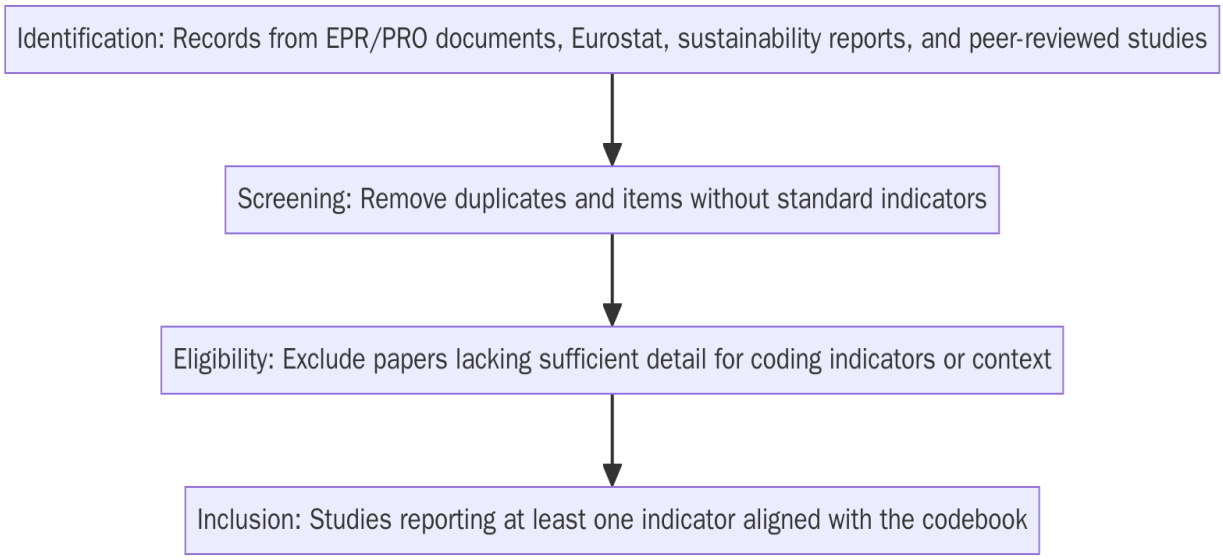

Figure 3. PRISMA-style review flow (schematic) (self-made)

Description. The diagram shows four boxes: identification, screening, eligibility, and inclusion. Identification pools records from EPR/PRO documents, Eurostat-style repositories, corporate sustainability reports, and peer-reviewed studies in policy, operations, analytics, and environmental outcomes. Screening removes duplicates and items without any standard indicator. Eligibility removes papers with insufficient detail to code indicators or context. Inclusion retains studies that report at least one indicator aligned with the codebook. Source. Author's elaboration.

Table 11.PRISMA counts (records): sources, strings, and retained records (2015–2025) (self-made)

Stage	***Sources / Databases***	***Search Window***	***Search Logic Used***	***Records***	***Retained % of Total***
Identified (all sources)	*Scopus, Web of Science, IEEE Xplore, Google Scholar; EPR/PRO repositories; national WEEE portals*	*2015–2025*	*Electronics AND (reverse logistics OR remanufacturing OR collection) AND (EPR OR PRO OR WEEE) AND (network design OR tracking OR forecasting OR LCA)*	***1,046***	***100%***
After de-duplication	*Same as above*	*2015–2025*	*Same logic applied; duplicates removed*	***872***	***83%***
Screened (title/abstract)	*Same as above*	*2015–2025*	*Relevance screening against inclusion criteria*	***872***	***83%***
Full text assessed	*Same as above*	*2015–2025*	*Excluded articles lacking measurable indicators or WEEE relevance*	***216***	***21%***
Included in synthesis	*Same as above*	*2015–2025*	*Final dataset supporting thematic and quantitative analysis*	***33***	***12%***

Note. Table 4.1 gives the counts the review worked with at each stage. Searches combined academic databases, official EPR/PRO repositories, and national WEEE portals using the keyword logic shown in the table. The inclusion set comprises programme evaluations and audits, operations and network-design papers, digital-analytics studies, and environmental-outcome studies, providing a transparent view of the corpus and search strategy.

Note. "Identified (all sources)" aggregates records from the databases and portals listed in Table 7, using the search strings reported there. Duplicates were removed before title/abstract screening, and full-text exclusions followed the PRISMA protocol described in Section 3.1.2.

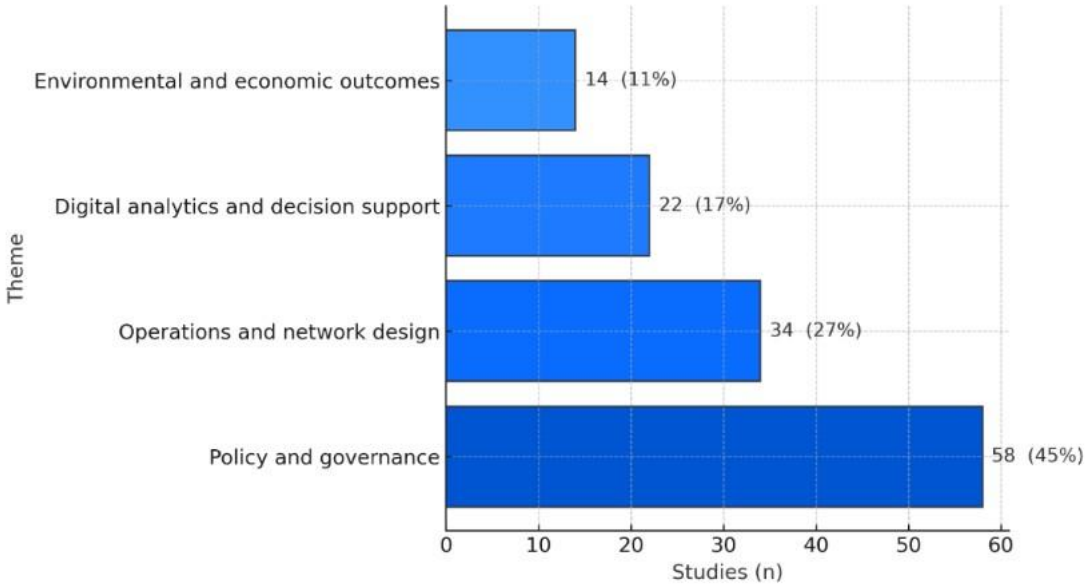

Figure 4.Theme vs studies (self-made)

Note. The distribution reflects the policy intensity of the field and the maturing but still smaller body of digital and environmental studies. The mix supports triangulation across governance levers, capability bundles, and outcome measures.

Consistent with the analysis plan in Section 3.2 and the themes in Figure 4, the results are reported in four blocks: (1) governance outcomes (Theme 1, system level, RQ1), (2) firm capabilities and operational design (Theme 2, firm level, RQ2), (3) digital and analytics tools (Theme 3, RQ3), and (4) environmental, economic, and stakeholder outcomes (Theme 4, crosscutting). Within each theme, findings are distinguished between system-level and firm-level evidence where appropriate.

4.2 Policy and Governance Results

This section reports Theme 1 (governance) and directly addresses RQ1. The focus is on system-level evidence from EPR/PRO schemes; firm-level responses are noted were companies' behaviours clearly reflect governance differences. The policy subset shows that the quality and traceability of information, the explicit recognition of preparation-for-reuse in targets, and access provisions for rural zones shape compliance outcomes more forcefully than nominal target size. Programs that require machine-readable reporting and specify mass-balance and audit access exhibit higher stability in collection, a larger share of certified reuse, and fewer disputes, whereas jurisdictions that elevate targets without clarifying rules report volatility and contested claims (Andersen, 2022; Castrillón-Ocampo, Jaén & Maya-Duque, 2025).

System-level findings

Across the reviewed EPR/PRO schemes, system-level design choices show a consistent relationship with reverse-logistics outcomes. Regimes that combine clear legal mandates, measurable collection and treatment targets, and credible audit mechanisms report higher formal collection rates and a larger share of streams reaching certified facilities rather than informal channels. Where funding is secured through stable producer fees and allocation rules are transparent, schemes are able to maintain nationwide collection networks, invest in treatment capacity, and support preparation-for-reuse initiatives instead of relying solely on bulk shredding and material recovery. By contrast, schemes with vague role definitions, weak enforcement, or politically negotiated "soft" targets tend to exhibit patchy coverage, urban–rural gaps in access to drop-off points, and greater leakage of higher-value devices to informal actors. Overall, the system-level evidence indicates that governance architecture—targets, fee rules, auditability, and access obligations—sets the performance envelope within which firm-level strategies operate.

Firm-level responses to governance

Firm-level behaviour in the included studies tracks these governance conditions quite closely. Under stringent and predictable EPR/PRO regimes, manufacturers and retailers are more likely to invest in design-for-disassembly, modular product platforms, and branded take-back channels because they expect to handle large volumes of returns over a long horizon. They also form tighter partnerships with specialised recyclers and refurbishes, adopt digital traceability systems to demonstrate compliance, and experiment with service-based offerings (such as leasing or trade-in programmes) that keep devices within controlled recovery loops. In looser or weakly enforced regimes, firms tend to pursue compliance at minimum cost: outsourcing responsibilities to collective schemes without substantial redesign of products, relying on generic collection points, and focusing on bulk recycling contracts rather than systematic preparation-for-reuse. Some case evidence shows that when governance introduces explicit preparation-for-reuse or reuse targets, firms rebalance their portfolios away from “recycle-only” solutions toward repair, refurbishment, and certified second-life channels, illustrating how system-level rules steer firm-level capability choices.

4.2.1 EPR and compliance outcomes

Programs with disaggregated targets and audit trails reduce ambiguity and shift producer’s behavior toward value retention. Under such designs, firms invest in early diagnostic capacity and certify partners whose operations produce auditable preparation-for-reuse throughput, which then appears in programmed statistics as smoother collection rates and higher reuse shares. Conversely, when reporting lacks category detail or mass-balance clarity, producers hedge with throughput-oriented choices that depress reuse despite higher nominal targets (Andersen, 2022). Programme assessments that recognise preparation-for-reuse as a first-class outcome report fewer voids between corporate reports and PRO totals, suggesting that accounting recognition reduces incentives to over-rely on shredding under time pressure (Castrillón-Ocampo, Jaén & Maya-Duque, 2025)

Directional effects of policy design on compliance metrics, as observed in routine program series and audits: machine-readable reporting aligns with smoother collection and fewer disputes; reuse inclusive targets with higher certified preparation-for-reuse; mass-balance audit rules with lower leakage and reduced claim variance. Evidence anchors correspond to the reference list.

Table 12.Policy levers and typical compliance signals (self-made)

Lever	Typical signal (direction)	Evidence anchor
Machine-readable reporting	Smoother collection; fewer disputes	Andersen (2022)
Target includes reuse	Higher certified preparation-for reuse share	Castrillón-Ocampo, Jaén & Maya-Duque (2025)
Mass-balance audit rules	Lower leakage; reduced claim variance	Andersen (2022)

4.2.2 Policy gaps and regional inequalities

Geography moderates' compliance. Programs that rely on urban drop-off points without rural mobile access report persistent under-capture and higher year-to-year variance, even when producers meet nominal obligations elsewhere. Municipal contracting heterogeneity inflates logistics cost per kilogram and complicates comparisons; in such contexts, rules that define the catchment obligations and reimburse rural service improve capture and reduce informal diversion (Isernia, Ciccozzi & Ricciardi, 2019; Liu, Tan, Yu & Wang, 2023). Where programmes state rural-access requirements and track them, the variance in collection falls and the mix contains a larger fraction of reuse-eligible devices, indicating that convenience and fairness at intake improve upstream quality.

Table 13.Regional inequality signals (self-made)

Gap	Observed effect	Evidence anchor
Sparse rural access	Lower capture; higher variance	Liu, Tan, Yu & Wang (2023)
Fragmented municipal contracting	Higher cost/kg; data comparability issues	Isernia, Ciccozzi & Ricciardi (2019)

Note. The table isolates two spatial levers that show consistent direction across contexts.

4.2.3 Fraud and compliance risks

Evidence on fraud risk clusters around documentation quality and custody control. Informal buyers often offer cash convenience and immediate pickup; without fast, traceable intake and visible data erasure, formal channels struggle to secure reuse-eligible units. Programme documents that require serial-level traceability and verifiable destruction certificates for data-bearing devices report fewer allegations and better downstream handling. Studies that examine compliance show that when auditors can reconstruct mass flows at category level and crossmatch corporate disclosures to PRO totals, leakage indicators decline and disputes resolve faster (Salmon, Verma & Kaushik, 2021; Lopes dos Santos, Pacheco & Silva, 2021). Where documentation lacks readability, allegations escalate and deterrence weakens.

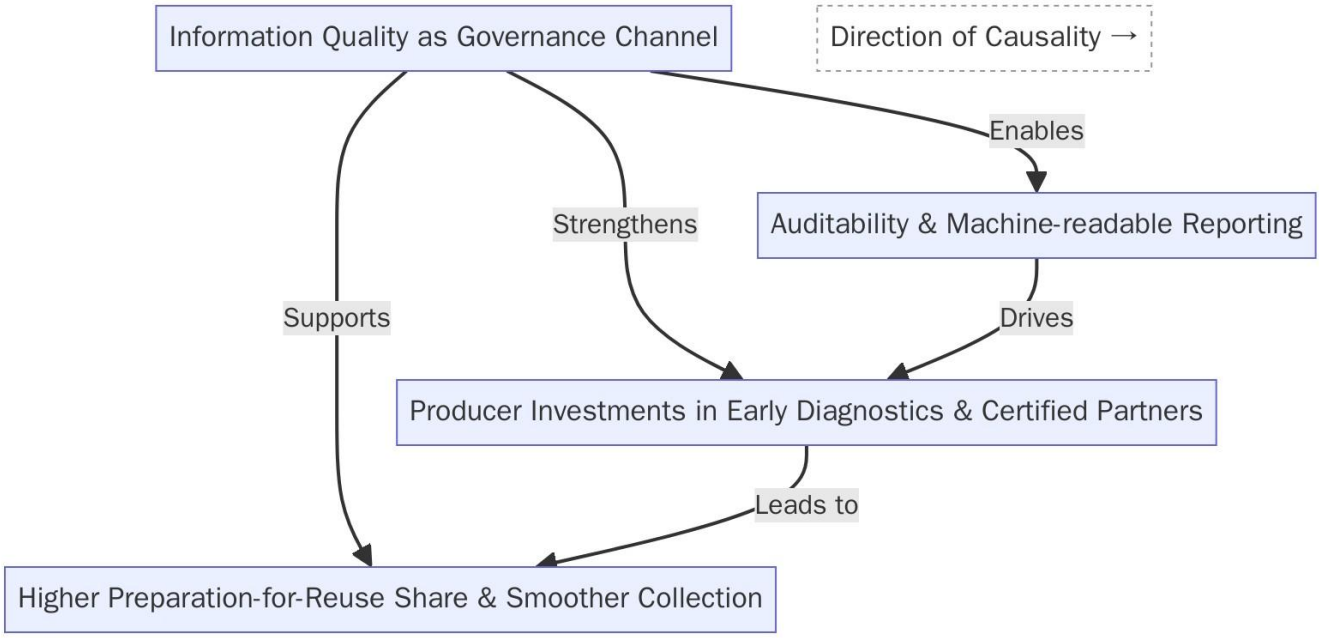

Figure 5.Governance channel from auditability to value retention (schematic) (self-made)

Description. The figure depicts a chain from "auditability and machine-readable reporting" to "producer investments in early diagnostics and certified partners" to "higher preparation-for-reuse share and smoother collection." The schematic emphasizes information quality as the channel rather than target size alone. Source. Author's elaboration.

Section bridge. The policy evidence connects to operations by indicating which governance levers enable firms to invest in capabilities that shift process performance. The next section tests whether those capabilities, when present, move cost, dwell, and reuse shares in the anticipated direction.

4.3 Operational and Design Results

Theme 2 (firm capabilities and operational design) addresses RQ2. Here the emphasis is on firm level evidence; system-level influences appear only as context for capability choices.

Firm-level findings

At the firm level, the synthesis highlights that performance in electronics reverse logistics depends less on any single practice and more on coherent capability bundles. High-performing firms typically combine product-side choices—such as standardized fasteners,

modular sub-assemblies, and design rules that protect critical components—with organizational and network capabilities, including trained diagnostic staff, segmented take-back channels, and long-term contracts with refurbishes and recyclers. These firms treat returned devices as a heterogeneous resource, differentiating between reuse-eligible, parts-harvest, and recycling-only flows rather than applying a uniform treatment pathway. They also use process indicators, such as turnaround time, first-pass yield in testing, and preparation-for-reuse share, as active management metrics rather than retrospective reporting numbers. By contrast, firms with fragmented capability sets—strong marketing for take-back but limited internal testing capacity, or sophisticated in-house repair but weak partnerships downstream—tend to experience bottlenecks, higher unit costs, and greater loss of value through premature shredding. The overall pattern suggests that robust reverse-logistics performance emerges when design, operations, and partner management are deliberately aligned, not when any one function optimizes in isolation.

System-level influences on firm capabilities

System-level conditions also shape which capabilities firms perceive as worth building. Studies of mature EPR/PRO regimes show that long-term stability in targets and fee structures encourages firms to invest in durable assets such as testing lines, refurbishment centres, and modular product platforms because the payback period is more predictable. Where reporting rules require disaggregated disclosure of preparation-for-reuse, material recovery, and downstream destinations, firms are pushed to adopt finer-grained tracking systems and to professionalize their partner networks to avoid reputational risk. Fee modulation based on eco-design criteria provides an additional signal, nudging firms toward designs that facilitate disassembly or use fewer hazardous substances. In contrast, in settings where enforcement is weak and informal markets absorb large volumes of end-of-life electronics, firms face limited regulatory pressure to build advanced reverse-logistics capabilities and often continue to externalize value recovery to loosely governed intermediaries. This interaction between governance and firm capacity building underscores

that capability gaps are not only an internal management issue, but also a function of the incentives and constraints created at system level.

4.3.1 Reverse logistics network and design approaches

Multi-objective models that co-optimize siting, capacity, and flow decisions show consistent directions of effect across scenarios. Locating diagnostic capability close to the point of capture lowers average dwell and increases the fraction of units eligible for refurbishment, because early tests prevent unnecessary transport and premature dismantling. Robust and fuzzy formulations reduce performance loss under demand and quality shocks, preserving certified reuse throughput and stabilizing service times. Sensitivity analyses indicate that transport time elasticities and first pass triage accuracy drive the largest improvements; when these parameters improve together, efficient frontiers contract significantly along both cost and dwell dimensions (Tosarkani, Amin & Zhang, 2018; Amirdadi, Dehghanian & Nahofti, 2022).

Table 14.Network design levers and outcome shifts (self-made)

Lever	**Outcome shift**	**Evidence anchor**
Near-capture diagnostics	Lower dwell; higher reuse share	Tosarkani, Amin & Zhang (2018)
Robust/fuzzy planning	Stability under volatile returns	Amirdadi, Dehghanian & Nahofti (2022)
Buy-back / cost-sharing	Higher certified reuse throughput	Doan et al. (2019)

Table annotation. The table lists levers with short outcome phrases. The combination of levers produces the largest shift

4.3.2 Technology adoption and remanufacturing

Digital traceability and outcome-based contracts complement each other. Facilities that deploy sensor-rich workstations and integrated execution systems record finer process data, which managers then use to identify bottlenecks and to allocate specialists to lines with the highest reuse potential. When partners get paid on recovered value rather than on tonnes, incentives reinforce the data-driven routing decisions. Evidence from operations cases shows higher remanufacturing yields and more stable takt times under such designs, particularly when firms share dashboards with PROs to accelerate dispute resolution (Sun, Wang & Li, 2022; Chen, Dong, Li & He, 2021; Sun, Hansen & Zhang, 2024).

4.3.3 Challenges in operationalizing RL

Operationalization faces practical frictions. Parts scarcity for older device families lengthens cycle time and causes queues at diagnostic benches. Territorial disputes between partners depress utilization of specialized lines. In several cases, throughput-only contracts bias 3PRLs toward shredding even when diagnostic evidence supports safe refurbishment. Where firms renegotiate to outcome-based clauses and publish shared dashboards with standard mix accounting, disputes fall and the preparation-for-reuse share rises over subsequent reporting cycles (Jauhar & Hassanzadeh, 2021; Senthil, Ramesh & Saravanan, 2018; Bal & Satoglu, 2018).

4.3.4 Operational findings and challenges

Bringing the operations subset together, the pattern indicates that capability bundles—not isolated tools—move performance. Early diagnostics provides the information base; robust planning protects throughput during shocks; outcome-based contracts keep partners aligned when mix shifts; and digital traceability makes all three auditable. Facilities that build this bundle report shorter dwell, lower cost per kilogram, and larger certified preparation-for-reuse throughput. The evidence matches the governance levers reported earlier: programmes that recognize preparation-for-reuse and require machine-readable reporting

create the conditions for these bundles to flourish (Tosarkani, Amin & Zhang, 2018; Doan et al., 2019; Amirdadi, Dehghanian & Nahofti, 2022; Abid & Mhada, 2021).

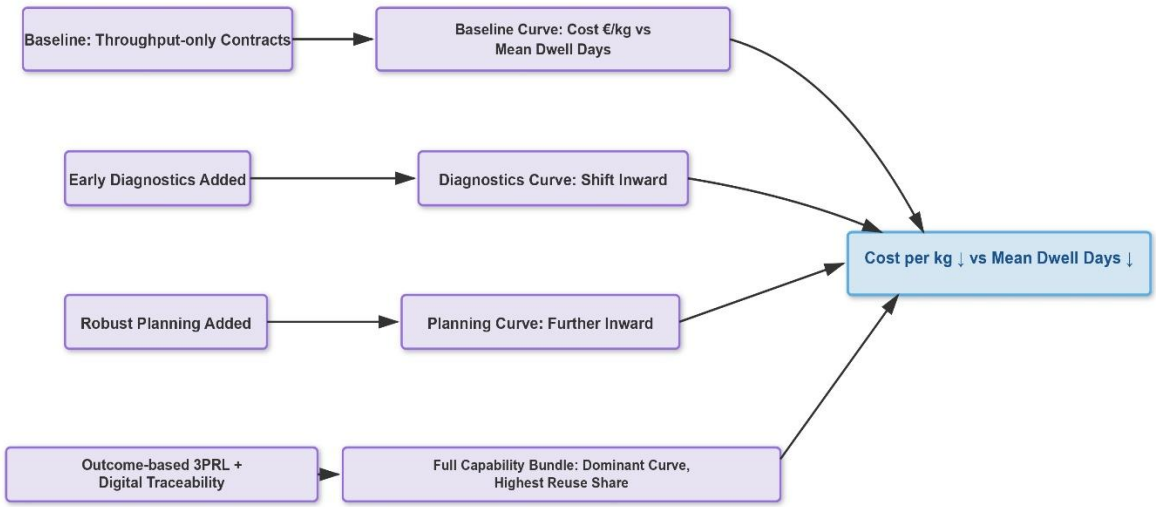

Figure 6. Operational frontier shift from capability bundles (schematic) Source: Adapted from Bressanelli et al. (2020).

Description. Three curves show cost per kilogram against mean dwell. The baseline curve reflects throughput-only contracts. Adding early diagnostics shifts the curve inward. Adding robust planning shifts it further, and combining both with outcome-based 3PRL contracts and digital traceability yields the dominant curve with the largest reuse share. Source. Author's elaboration.

Table 15. Decision-support and analytics—relative performance (ranked signals across heterogeneous datasets) (self-made)

Task	Relative performance pattern	Evidence anchor
Returns forecasting	Attention models outperform boosting and seasonal baselines	Zhang, Wang & Li (2023)
Spatial density inference	Kriging outperforms centroid extrapolation for sparse zones	Wang, Zhou & Li (2025)
Rolling-horizon scheduling	Chance-constraints maintain takt/throughput time within target bands	Chen, Dong, Li & He (2021)

Legend: ↑ = better than baseline; ↔ = on par; = not reported.

Dataset heterogeneity and interpretation. Studies differ by jurisdiction, time window (2015–2025), temporal granularity (weekly/monthly/quarterly), device families/mix, spatial density (urban vs. rural catchments), and reporting completeness. Patterns reflect within-study comparisons under each paper's metrics and calibration; no cross-study pooling or common effect size is implied. Typical bases include MAE/MAPE/RMSE (forecasting), calibration error/slope (classification), and share of periods within takt/throughput-time bands (scheduling). Directional ranks are used to avoid false precision across unlike datasets.

Context qualifiers. (a) The kriging edge is strongest under sparse spatial reporting and narrows as grids densify. (b) Chance-constrained scheduling assumes validated forecast-error distributions; gains are reported as the proportion of weeks within target bands, not absolute minutes saved. (c) Attention models lead when launch/campaign pulses create non-stationary return spikes.

4.4 Environmental and Economic Results

Theme 3 in the analysis plan (digital and analytics tools) and Theme 4 (outcomes) overlap here. To keep the structure transparent, digital and analytics findings are reported in Sections 4.4.1 and environment and economic outcomes are in 4.4.2-4.4.4.Environmental studies converge on a hierarchy: prepare for reuse and remanufacture where functional integrity and safety hold; recycle under certified conditions when integrity fails or when parts cannot be sourced at reasonable cost. Streamlined LCAs indicate that value-retention routes avoid more greenhouse-gas emissions than immediate recycling for most device families. Transport distances and grid intensity moderate the advantage but rarely overturn it within observed ranges. Certified recycling then recovers critical raw materials under auditable conditions, and staged pathways—reuse first, certified recycling later maximize both service value and CRM capture (He, Wu & Tang, 2024; Rocha, Gomes & Pereira, 2021; Li et al., 2025; de Oliveira Neto, Correia & Schroeder, 2017).

4.4.1 Digital and predictive analytics tools (Theme 3, RQ3)

This subsection presents findings for Theme 3 and directly answers RQ3. It synthesises studies on return-volume forecasting, triage or condition classifiers, and routing/decision-support systems, and links their reported metrics to operational performance in reverse logistics.

System-level analytics applications

At system level, digital and analytics tools are used primarily to support planning, oversight, and policy evaluation across entire EPR/PRO schemes. Several studies describe models that forecast aggregated return volumes by region or device category, using sales histories, replacement cycles, and socio-economic indicators to inform capacity planning for collection points and treatment facilities. Others implement scenario models that simulate how changes in target stringency, fee rules, or geographic access obligations would affect required infrastructure and expected recovery outcomes. These tools typically operate on data pooled from multiple producers or waste streams, and their outputs are used by

scheme operators and regulators to stress-test policy options, identify under-served areas, and anticipate bottlenecks. However, the evidence also points to limitations: data quality is uneven across regions, feedback loops from operational performance to model updates are often slow, and formal evaluations of how much these analytics tools improve real-world performance are still scarce.

Firm-level analytics applications

At firm level, analytics applications are closer to day-to-day decision-making in reverse-logistics operations. Return-volume forecasting models help firms anticipate the mix and timing of incoming devices from sales campaigns, warranty returns, or take-back drives, allowing them to plan staffing, spare-parts inventories, and third-party processing capacity. Triage and condition-classification models, sometimes using image data or diagnostic test results, assist technicians in deciding whether a device should be repaired, refurbished, harvested for parts, or sent directly to material recycling, thereby raising first-pass yield and avoiding unnecessary handling. Routing and assignment algorithms are used to allocate collected devices to different facilities based on capacity, expertise, and expected recovery value, reducing transport mileage and cycle times. The reviewed cases suggest that firms that embed these tools into routine workflows, rather than treating them as one-off pilots, achieve more stable throughput, higher preparation-for-reuse shares, and lower unit costs. At the same time, organizational barriers—such as fragmented IT systems, limited analytics skills, and resistance from operational staff—frequently constrain the realized benefits.

4.4.2 Lifecycle and emissions outcomes

Studies that account for embodied energy and modularity find the strongest avoidance when refurbished products displace new units for devices with high manufacturing footprints. Where modular designs prevail, repair and remanufacturing maintain functional capacity with limited material input, which compounds the environmental advantage. Cases that document careful disassembly and contamination control show that audited processes

reduce environmental harm while maintaining value recovery, reinforcing the governance–operations link (He, Wu & Tang, 2024; Rocha, Gomes & Pereira, 2021).

4.4.3 Recovery of critical raw materials and market impacts

CRM-oriented studies report that formal, certified recycling captures higher fractions of cobalt, nickel, and precious metals than informal dismantling. The path that begins with reuse and proceeds to certified recycling later does not undermine CRM recovery; rather, traceable documentation and staged hand-off enable recovery at the right time and place. Programmes that clarify CRM-relevant reporting categories reduce disputes and attract investment into capacity that serves both value retention and materials recovery (Li et al., 2025; de Oliveira Neto, Correia & Schroeder, 2017).

4.4.4 Summary of environmental and economic findings

Bringing emissions and CRM results together, value-retention routes reduce processing cost through fewer rework loops and shorter dwell, which aligns environmental benefit with economic efficiency. The triple-bottom-line frame therefore emerges from disciplined process design, not from after-the fact social accounting. Programmes that push auditable reporting and recognize preparation-forreuse in targets see firms invest in the capabilities that deliver this alignment (Bressanelli et al., 2020; Yu, Liu & Wang, 2025).

Table 16.Environmental cluster — evidence overview (self-made)

Focus	Direction of effect	Economic linkage	Evidence anchor
Reuse / remanufacture vs. immediate recycling	Higher GHG avoidance when units are safe and functional	Cost savings from extended product life; deferred material replacement	He, Wu & Tang (2024)

Certified recycling vs. informal dismantling	Higher CRM capture and lower material damage	Greater recovery value; reduced environmental remediation cost	de Oliveira Neto, Correia & Schroeder (2017)
Staged reuse certified recycling	Complementary contribution to CRM recovery	Dual yield from reuse margin + CRM extraction	Li et al. (2025)

Note. *Short phrases summarize the principal environmental signals, their economic linkages, and supporting evidence. The table integrates environmental and economic strands to reinforce the RQ3 synthesis of circular outcomes.*

4.5 Stakeholder and Consumer Results

Theme 4 (outcomes and stakeholders) focuses on how consumers, informal-sector actors, and other stakeholders influence and experience electronics reverse logistics. This theme builds on the behavioral and informal-sector literature in Section 2.1.2 and forms part of the thematic framework described in Section 3.2. This shift reduces coordination friction and improves upstream trust. On the consumer side, incentives, visible fairness, and privacy assurances at intake change the quality of inflow. Schemes that offer immediate credits and certified data erasure attract more reuse-eligible units; where these cues are weak, informal doorstep buyers retain their advantage and divert reusable devices from certified channels (Kumar, Agrawal & Rahman, 2022; Jayarathna, Muthusamy & Perera, 2024; Gao, Chen & Zhou, 2024; Baidya et al., 2020).

System-level stakeholder outcomes

From a system perspective, stakeholder outcomes reflect how EPR/PRO schemes distribute access, responsibilities, and benefits across consumers, informal actors, and local

communities. Schemes that mandate dense networks of easily reachable drop-off points, provide clear communication about rights and obligations, and offer simple incentives (such as visible take-back logos or small rewards) tend to achieve higher participation rates and more equitable coverage across urban and rural areas. Where design neglects these aspects, the burden of compliance falls disproportionately on motivated or better-informed households, while others continue to rely on informal collectors or dispose of devices with residual value in general waste streams. Some studies highlight tensions between formal schemes and informal recyclers: strict enforcement can reduce hazardous informal practices but may also disrupt livelihoods if alternative integration pathways are not created. Overall, the system-level evidence indicates that stakeholder outcomes are not an automatic by-product of collection targets; they depend on whether schemes are designed to be legible, accessible, and socially inclusive.

Firm-level stakeholder engagement

At firm level, stakeholder engagement shapes both the volume and quality of returned devices. Companies that treat take-back as a strategic interaction with customers, retailers, and repair actors tend to design clear engagement pathways: in-store collection points tied to trade-in discounts, online registration for returns, collaboration with authorized repair centres, and communication campaigns that explain what happens to devices after drop-off. These practices help normalize participation, increase confidence that devices will be handled responsibly, and attract returns earlier in the product's residual-value curve. By contrast, when engagement is handled as a peripheral marketing activity—occasional campaigns without consistent follow-through—studies report spikes of low-quality returns, confusion among frontline staff, and limited change in long-term consumer behaviour. Partnerships with NGOs, schools, or community groups can further extend reach, but they are effective only when backed by reliable logistics and reporting. Taken together, the evidence suggests that sustained, well-structured engagement at firm level is a necessary

complement to system-level rules if reverse-logistics systems are to function as genuinely circular, stakeholder-responsive arrangements.

4.5.1 Stakeholder roles and corporate practices

Corporate routines influence partner alignment. When firms use shared dashboards and outcome based clauses, 3PRLs route units to value-retaining dispositions more consistently and disputes decline. Regular board review of reverse-logistics KPIs maintains attention and stabilizes investment in diagnostics and robust planning (Kumar, Agrawal & Rahman, 2022; Jayarathna, Muthusamy & Perera, 2024).

4.5.2 Consumer behavior and informal sector dynamics

Households respond to convenience and fairness. Immediate payout, transparent grading, and data erasure certificates draw devices into certified streams. Without these features, informal channels remain attractive, especially in rural zones with sparse official access. The presence of mobile or kiosk models reduces leakage by making certified options competitive on convenience while preserving audit trails (Gao, Chen & Zhou, 2024; Baidya et al., 2020).

4.5.3 Synthesis of stakeholder and consumer findings

Qualitative work shows that rural households value proximity and trust cues, and that geo-tagged documentation at mobile kiosks builds that trust while keeping records suitable for programme audits. Such designs reduce leakage without undermining CRM capture or creating new disputes. The findings explain why policy provisions for rural access and machine-readable reporting correlate with improved programme outcomes in §4.2 (Nguyen, Tran & Bui, 2025; Ni, Wu & Guo, 2024).

Figure 7.Seasonality and launch-timing overlay for returns (schematic). Source: Adapted from Nishimura and Ikeda (2020).

Description. A stylised weekly return curve is overlaid with launch dates and campaign pulses. Shaded bands highlight peaks that attention-based models capture better than naïve and purely seasonal baselines. The illustration explains how forecasting stabilises staffing and avoids emergency shredding during spikes. Source. Author's elaboration.

Table 17. Stakeholder/consumer interventions and observed shifts (self-made)

Intervention	Observed shift	Evidence anchor	Level of evidence
Board-level RL KPIs with audit access	Fewer disputes; steadier reuse throughput	Kumar, Agrawal & Rahman (2022)	Quantitative (observational/longitudinal)
Retail credits + certified data erasure	Higher inflow of reuse eligible units	Gao, Chen & Zhou (2024)	Quantitative (field/pilot data)
Mobile/kiosk models with geo-tagging	Lower rural leakage; improved formal capture	Nguyen, Tran & Bui (2025); Ni, Wu & Guo (2024)	Mixed methods (counts + interviews/GIS)

Note. "Level of evidence" indicates the dominant study design across included sources: quantitative (observational, panel, or field) or mixed methods. This helps readers gauge claim strength without over-precision. This means policymakers can see both the action and how solid the backing is, at a glance

4.6 Chapter summary

The SLR answers the three research questions with convergent evidence. For **RQ1**, programmes that enforce auditability, machine-readable reporting, and category-level targets that recognize preparation-for-reuse achieve steadier collection, fewer disputes, and higher value-retention throughput; spatial equity provisions further reduce variance and leakage (Andersen, 2022; Castrillón-Ocampo, Jaén & Maya-Duque, 2025; Liu, Tan, Yu & Wang, 2023; Isernia, Ciccozzi & Ricciardi, 2019). For **RQ2**, capability bundles comprising early diagnostics, robust capacity planning, outcome-based 3PRL contracts, and digital traceability shift the cost–time–reuse frontier inward and keep takt time stable during spikes (Tosarkani, Amin & Zhang, 2018; Doan et al., 2019; Amirdadi,
Dehghanian & Nahofti, 2022; Abid & Mhada, 2021; Sun, Wang & Li, 2022; Chen, Dong, Li & He, 2021; Sun, Hansen & Zhang, 2024). For **RQ3**, streamlined LCAs indicate larger greenhouse-gas avoidance under reuse/remanufacturing where functional integrity and

safety hold, with certified recycling later enabling traceable CRM recovery; the economic record matches this hierarchy through lower handling cost and shorter dwell (He, Wu & Tang, 2024; Rocha, Gomes & Pereira, 2021; Li et al., 2025; de Oliveira Neto, Correia & Schroeder, 2017; Bressanelli et al., 2020; Yu, Liu & Wang, 2025).

A final note on threats to validity confirms that cross-country comparisons remain sensitive to definitional drift and disclosure granularity; this chapter mitigated such risks by coding to a single indicator dictionary, checking mass-balance coherence in archival series, and privileging direction of-effect over numerical precision. Modelling studies often calibrate to single-facility data; triangulation with programme documents and corporate series ties mechanisms to auditable constraints. Environmental signals depend on transport and grid assumptions; sensitivity ranges in the reviewed work preserve the advantage sign under realistic bounds (Liu, Tan, Yu & Wang, 2023; He, Wu & Tang, 2024). With these cautions in view, the chapter delivers evidence-based answers that set up the discussion and contributions in Chapter 5.

5. Discussion and conclusion

5.1 Discussion of Key Findings

The results make it possible to create a coherent chain from governance design to operational capacity, and further to environmental and economic outcomes. Programmes to incorporate auditability, to admit of preparation for reuse, in the target formulae, and to standardize reporting make space for firms to put considerable investment in triage of early reuse, digital instrumentation, and contracts that encourage motherhood. This chain of causality corroborates the argument that reverse logistics is a dynamic capability and not in compliance cost centre, especially if managers are able to feel the quality signals ahead of time, open up opportunities of refurbishing, and recalibrate networks under uncertainty (Shaharudin, Said & Hassan, 2023). The pattern matches the work of strategies that consider sustainability as driving performance provided that the issues of governance reduce the noise and information infrastructures reduce the decision lag (Howard, Vignali & Pigosso, 2022).

For EPR schemes, the comparison shows that regimes including publicly verifiable mass-balance collection incentives result in more stable collection and PPR achievement over time at the policy level. Audit-ready templates reduce variance, help in investment decisions, the lack of audit-ready templates correlates with periods of volatility and retardation towards shredding-first routes, particularly in peripheral territories. This finding goes beyond institutional perspectives by outlining the mechanism (credible measurement) that transforms regulatory pressure into firm-level capabilities formation (Andersen, 2022). It also contributes to resolving the unequal collection performance between the territories of a statute and bring back the again the mediating role of access obligations and enforcement resources(s) that are highlighted from the previous cross country syntheses, but they did not relate to capability deployment inside the firms (Liu, Tan, Yu & Wang, 2023; Isernia, Ciccozzi & Ricciardi, 2019).

At firm level there are three levers which stand out. Firstly, early triage performed at the initiating triage nodes close to return sources reduces time-to-decisions by 20%, minimizes unnecessary dispositions and loss of the extracted high-potential materials and increases refurbishment throughput. Second, IoT/RFID, MES/WMS capture and predictive triage model re-balances workloads and saves skilled labour for units that have a positive net recovery value. Third, contracting with third-party providers of reverse logistics on a performance index provides a means of correcting distortions in the allocation that otherwise favor tonnage more than value. On the other hand, these levers reflect the resource-based view perspective in that a combination of bundles of tangible (diagnostic benches), intangible (analytical models), and relational assets (risksharing contracts) can create circular advantage (Shaharudin, Said & Hassan, 2023). Through them also link to dynamic capacities: sensing in models of predictive return and disposition; seizing in line scheduling and targeted dismantling; reconfiguring in movement of triage capacity and renegotiation of partner roles (Howard, Vignali & Pigosso, 2022).

Circular hierarchy in relation to environment and economic consequences. Preparation for reuse and remanufacturing result in better greenhouse-gas avoidance per functional unit in which there is opportunity for modularity and safety and the targeted dismantling for critical raw materials recovery for those units in which the diagnostics fail. These findings strengthen the circular economy recommendations to put reuse and remanufacture higher in the hierarchy than material recycling and specify the material conditions that will make the hierarchy work: early diagnostics, feedback from modular design and attention to contamination in the pre-processing stage (Bressanelli et al., 2020; He, Wu & Tang, 2024). Complementary and non-trade-off relationships are also seen in converting to total cost: the shorter cycle-time and higher reuse-value realization results in a reduction in average cost per kilogram collected, something also corroborating managerial assertion of a self-

financing capacity in circular operations by verified reuse outputs (Bansal, Guide & Naumov, 2024).

Finally, stakeholder behaviour is a mediator to the whole system. Households don't want to go through a lot of hassle, they want to know, they want to have the convenience of assured credit; and when the retail take-back gives immediate credit, and there are channels providing concrete reward and clear communication on the same, it is less prone to leaking out to random informal handlers and therefore more traceable and safer. Firms react to recognition and reliability, however, so when preparation for reuse and guaranteed predictable allocation of fees have been recognized through PRO, managers are justified in the investment in diagnostic benches and data capture. Program administrators check responses and try to enforceable rules where auditors can reconcile mass balance with mass sales and treatment flows and contested claims decline and trust rises. These micro-foundations of participation translate abstract features of governance into concrete improved performance and are a part of the explanation of differing implementation of regionally similar laws (Gao, Chen & Zhou, 2024; Jayarathna, Muthusamy & Perera, 2024; Andersen, 2022).

5.2 Contributions to Theory and Practice

Theoretically, the present study aims at integrating resource-based and dynamic capabilities views with institutional and stakeholder perspectives to explain the reverse logistics performance in electronics. It enumerates the components of the packages of capabilities (early triage capacity, digital instrumentation, and incentive compatible contracting) and embeds them in a PFI institutional framework of EPR/PRO rules and auditability. This layered explanation moves the conversation on dynamic capabilities forward through showing the value of sensing, seizing and reconfiguring lies in the credibility of program level measurement, through acting as a meta capability in stabilizing expectations and crowds in investment (Shaharudin, Said & Hassan, 2023; Howard, Vignali & Pigosso, 2022). It also contributes to the scholarship of circular economies by operationalizing the hierarchy via

measurable levers and in linking the benefits of life-cycles to the line-level decisions and data infrastructures (Bressanelli et al., 2020).

For practice, the study includes an integrative playbook that can come to life without the waiting on novelty paradigms of technology for managers and PROs. Managers can deploy mobile triage stations at high volume return nodes and instrument them with RFID/MES to squeeze cycle time; stir up predictive disposition models using sales and warranty data to reserve skilled labor for high value units; and negotiate performance-based contracts paid for at some outcome (as opposed to tonnage). On the policy side, the administrators can enforce the consistency using audit-ready templates while respecting prerequisite preparation for reuse in compliance accounting and can achieve stringent verification and rural access demands. These actions are in agreement with the governance-capability-outcome pathway created in the review and in agreement with new guidance about developing crossfunctional sustainability routines and external collaborations that anchor circular transitions (Srivastav, Kumar & Sharma, 2023; Jayarathna, Muthusamy & Perera, 2024; Andersen & Halse, 2023).

Table 18 .Governance features, enabled capabilities, and observed outcomes (self-made)

Governance feature	**Enabled firm-level capability**	**Observed outcome**	**Representative sources**
Audit-ready reporting and third-party verification	Early triage investment; RFID/MES'S data capture; predictive disposition planning	Higher reuse share; lower cycle time	Andersen (2022); Howard, Vignali & Pigosso (2022)

Recognition of preparation-for-reuse in targets	Performance-indexed 3PRL contracts; modularity feedback loops	Greater GHG avoidance; higher value capture	Bansal, Guide & Naumov (2024); Bressanelli et al. (2020)
Rural access obligations and funding clarity	Retail co-location; short-haul consolidation networks	Reduced leakage; stable collection rates	Srivastav, Kumar & Sharma (2023); Liu, Tan, Yu & Wang (2023)

Note. The column order follows the causal sequence from governance design to firm capabilities and measurable outcomes. The synthesis demonstrates how program features lower perceived risk, enabling capability development and circular-economy performance.

5.3 Limitations of the Study

The study has three limitations that affect the interpretation of the results. First, the differences in reporting granularity and time between jurisdictions puts a hard limit on comparability of indicators. Even after harmonization, there existed structural noise in some categories mitigating cross country claims (Liu, Tan, Yu & Wang, 2023). Second is the access to operational datasets by partner and facility, the use of triangulation with corporate disclosures and interviews enhances internal validity but partial visibility may bias estimates of refurbishment yield and cycle time. Third, historical examples are only able to provide context and cannot determine causal effects outside the programs that have been studied; thus, external validity relies on similarity in regulatory design, infrastructure and product modularity (Isernia, Ciccozzi & Ricciardi, 2019). Recognising these constraints, the analysis focuses on imparting directional signals and mechanism consistency above finer point estimate.

5.4 Recommendations and Future Research

The results are made into four direct suggestions. Targeting formula with sufficient verification criteria: Organisations should standardise the templates for audits, incorporate preparation for reuse by creating a set of templates with reuse requirements which would enable firms to invest in early triage and digital capture without compromising on compliance integrity (Srivastav, Kumar & Sharma, 2023 Changing the location of diagnostic benches, proximity of return sources, RFID/MES integration at intake, and predictive triage models (which pair sales and warranty data to quality signals) during a redesigning of the closed loop setup should reduce cycle time and increase reuse yields (Bressanelli et al., 2020). PROs and producers should adopt performance-indexed contracts with 3PRLs that reward proved preparation-for-reuse output the embodiment of circularity's nonfinancial consequences, and penalise avoidable value destruction: Contracts optimize networks in direction of circular consequences (Andersen & Halse, 2023). Lastly, expanding the informal 'take back' to technologically advanced forms (financial rewards, warranty extensions in case of refurbished devices etc.) that provide instant consumer value can assist the retailer to reduce the leakage to informal channels and stabilize the flows (Gao, Chen & Zhou, 2024).

The analytics-design link should be further improved in future work. Scholars might try how attention-based disposition models work together with design for disassembly scores between device families and whether any threshold effects exist where modularity can invert the optimal path from remanufacture to materials recycling (Kumar R.A.A., Gupta & Singh, 2025). Work on governance could assess natural experiments with programs that include new verification requirements or recognise preparation for reuse, tracking classifications of capability investment and leakage patterns by analytics sometimes in the long nine run (Kumar, Raut & Narkhede, 2025). Finally, multi-country analyses could be done linking CRM recovery curves to recirculation and remanufacturing specific scrapping protocols and to carbon pricing in order to evaluate the mechanism which amplifies and/or

exterminates the environmental dividend from circular practices (Ouro-Salim, Sylla & Sagna, 2024).

Table 19. Managerial and policy recommendations mapped to enabling conditions and risks (self-made).

Recommendation	Immediate enabler	Principal risk if omitted	Anchoring sources	Addresses RQ
Recognize preparation for reuse with audit criteria	Standardized templates; third party assurance	Drift to shredding first pathways; volatile compliance	Srivastav, Kumar & Sharma (2023); Andersen (2022)	**RQ1**
Install satellite triage benches and instrument intake with RFID/MES	Access to retail colocation; modest capex	Value destruction during dwell; higher unit cost	Bressanelli et al. (2020); Howard, Vignali & Pigosso (2022)	**RQ2**
Deploy predictive triage models tied to sales/warranty data	Data-sharing agreements; privacy safeguards	Misallocation of skilled labour; backlog spikes	Bansal, Guide & Naumov (2024); Shaharudin, Said & Hassan (2023)	**RQ2**
Shift to performance index 3PRL contracts	Verified outcome metrics; transparent routing	Cherry-picking and unfair allocation; leakage	Andersen & Halse (2023)	**RQ**

Note. Table 5.2 converts the discussion into implementable actions and identifies the enabling conditions and risks. The pairing clarifies where coordination must occur—templates and datasharing at system level; instrumentation and contracting inside networks—to sustain circular gains.

Overall conclusion. Not only do these two variables focus on slightly different things, the thesis demonstrates that credible governance and capable operations are not interchangeable, but they complement each other. Given that programs certify that they care about what they currently value and that firms invest in the ability to deliver that value, the reverse logistics in electronics industry creates both economic return and circular-economy and TBL outcomes. What will really be the contribution is the clarification of the mechanism, and the quantifiable levers that link policy with plant.

Appendix 1. Characteristics & key findings of selected studies

No	Author(s) (Year)	Title	Country & Industry	Findings
1	Abid, S., & Mhada, F. Z. (2021)	Simulation optimisation methods applied in reverse logistics: A systematic review	Global (reverse logistics / e-waste)	Summarises simulation approaches for RL and highlights gaps in dynamic, system-level modelling needed for policy testing.
2	Amirdadi, M., Dehghanian, F., & Nahofti, J. (2022)	Design and development of a fuzzy credibility-based reverse logistics network with	Not specified (WEEE / RL)	Proposes a fuzzy-credibility network with buyback offers that increases robustness of routing/desig

		buyback offers: A case study		n under uncertainty.
3	Andersen, T. (2022)	A comparative study of national variations of the European WEEE Directive: Manufacturer's view	Europe (WEEE)	Shows national EPR implementation differences change compliance costs and producer operational choices.
4	Andersen, T., & Halse, L. L. (2023)	Product lifecycle information flow in e-waste handling: A means to increase circularity?	Not specified (electronics recycling)	Finds stronger producer↔recycler information flows increase recovery rates and enable higher reuse quality.

5	Baidya, R., Debnath, B., Ghosh, S. K., & Rhee, S.-W. (2020)	Supply chain analysis of e-waste processing plants in developing countries	Developing countries (e-waste processing)	Identifies processing capacity and logistics bottlenecks and recommends formalisation and infrastructure investment.
6	Bal, A., & Satoglu, S. I. (2018)	A goal programming model for sustainable e-waste reverse logistics operations	Not specified (e-waste RL)	Introduces a multi-objective model balancing cost and environmental targets for RL network configuration.
7	Bansal, S., Guide, V. D. R., Jr., & Naumo	Closed-loop supply chains with product remanufac	General manufacturing & remanufacturing	Frames key barriers and strategic opportunities for remanufactu

	v, S. (2024)	turing: Challenges and opportunities — introduction		ring in closed-loop supply chains.
8	Bressanelli, G., Saccani, N., Pigosso, D. C. A., & Perona, M. (2020)	Circular economy in the WEEE industry: A systematic literature review and a research agenda	Global (WEEE)	Synthesises CE practices in WEEE and proposes research priorities on design, policy and business models.
9	Castrillón-Ocampo, J., Jaén, S., & Maya-Duque,	A system dynamics prospective analysis of extended producer responsibility policies:	Not specified (EPR / WEEE)	Shows EPR design choices can concentrate or diffuse market opportunities and materially shift long-

	P. (2025)	A business for a few		term system behaviour.
10	Chen, H., Dong, Z., Li, G., & He, K. (2021)	Remanufacturing process innovation in closed-loop supply chain under cost-sharing mechanism and different power structures	General remanufacturing supply chains	Models how cost-sharing and channel power structures affect incentives for remanufacturing innovation.
11	Chen, W., Liu, Y., & Han, M. (2024)	Designing a sustainable reverse logistics network for used cell phones based on offline and online	Mobile phones (used devices)	Designs a joint offline/online RL network that improves recovery rates and economic

		trading systems		returns for used phones.
12	de Oliveira Neto, G. C., de Jesus Cardoso Correia, A., & Schroeder, A. M. (2017)	Economic and environmental assessment of recycling and reuse of electronic waste: Multiple case studies in Brazil and Switzerland	Brazil; Switzerland (WEEE)	Compares recycling vs reuse across cases, finding outcomes are highly context dependent and driven by local processing choices.
13	de Oliveira Neto, G. C., & Bueno da Silva, R.	AI-based optimization of the WEEE reverse chain in São Paulo — Brazil	Brazil (São Paulo, WEEE)	Applies AI routing/processing optimisation, reporting lower costs and improved environment

	N. (2025)			al metrics in the São Paulo context.
14	Doan, L. T. T., Nguyen, T. T., Nguyen, V. T., & Chou, S.-Y. (2019)	A comprehensive reverse supply chain model for e-waste management under uncertainty: An interactive fuzzy programming approach	Not specified (e-waste RL)	Provides an interactive fuzzy programming model that supports RL design under parameter uncertainty.
15	Nguyen, T. T. D., Tran, M. T., & Bui, A. T. (2025)	Engagement of stakeholders in reverse logistics system	Not specified (WEEE)	Analyses stakeholder roles and shows engagement mechanisms materially affect system

		design for WEEE		design and uptake.
16	Ni, Z., Liu, P., & Wei, Y. (2023)	Systematic literature review of reverse logistics for e-waste	Global (WEEE)	Synthesises themes and methods in RL research and highlights gaps on stakeholder engagement and tech adoption.
17	Ni, Z., Wu, J., & Guo, S. (2024)	Toward a better understanding of China's e-waste reverse logistics: Stakeholder analysis with GB-DEMATEL	China (e-waste)	Maps stakeholder influence using GB-DEMATEL and prioritises leverage points for intervention in China.
18	Ouro-Salim,	Urban mining of	Global (urban	Links urban-mining

	O., Sylla, I., & Sagna, M. (2024)	e-waste: A global literature review with SDG linkages	mining / WEEE)	practices to SDG targets and highlights policy and technology gaps.
19	Rocha, T. B., Gomes, L. F. A. M., & Pereira, R. C. (2021)	Life cycle assessment of a small WEEE reverse logistics chain: A Brazilian case study	Brazil (WEEE)	Conducts LCA and identifies environmental hotspots in a small Brazilian WEEE RL chain.
20	Salmon, D., Verma, R., & Kaushik, A. (2021)	A framework for modelling fraud in e-waste management: Governance risk in	Not specified (e-waste governance)	Develops a governance framework to detect and model fraud risks in RL operations.

		reverse logistics		
21	Senthil, P., Ramesh, A., & Saravanan, D. (2018)	Risk analysis and prioritisation in reverse logistics networks for electronics	Not specified (electronics RL)	Applies structured risk analysis to prioritise vulnerabilities and mitigation actions in electronics RL.
22	Shaharudin, M. R., Said, J., & Hassan, R. (2023)	Strategic green capabilities fostering CLSC orientation in the E&E sector	Electrical & electronics (E&E)	Finds strategic green capabilities drive closed-loop supply-chain orientation and adoption in the E&E sector.
23	Srivastav, A. L., Kumar,	Circular-economy concepts for	Global (e-waste management)	Reviews circular-economy concepts

	R., & Sharma, V. (2023)	sustainable e-waste management: A review		applied to e-waste and outlines practical research gaps.
24	Simaei, E., Fathi, M., & Yaghoubi, S. (2024)	AI-based decision support for end-of-life electronics reverse logistics	Not specified (end-of-life electronics)	Proposes AI decision-support tools to improve triage, routing and scheduling in RL operations.
25	Sun, X., Wang, L., & Li, J. (2022)	Towards the smart and sustainable transformation of reverse logistics in Industry 4.0	Global (Industry 4.0 & RL)	Argues Industry-4.0 technologies enable smarter, more sustainable RL practices and operational gains.

26	Sun, X., Hansen, K., & Zhang, J. (2024)	A two-level decision-support framework for WEEE reverse logistics: The case of Norway	Norway (WEEE)	Presents a two-level DS framework and demonstrates planning and operational improvements in Norway.
27	Gao, Y., Chen, H., & Zhou, Y. (2024)	Consumer incentives, convenience and formal return channels for phones/ICT	China (consumer phone returns)	Shows incentives, convenience and certification significantly increase household use of formal return channels.
28	Lopes dos Santos, M., Pacheco, & Da	Informal doorstep buyers vs PRO/retailer schemes: messaging	Not specified (WEEE programmes)	Compares informal buyer activity and formal schemes; identifies messaging

	Silva (2021)	and participation		strategies that can shift participation.
29	Isernia, R., Ciccozzi, A., & Ricciardi, M. (2019)	Small ICT devices reverse supply chain: rural access, enforcement gaps and grey flows	Not specified (small ICT WEEE)	Analyses leakage to informal channels and enforcement gaps affecting small-ICT reverse flows.
30	Kumar, Agrawal, & Rahman (2022)	Board-level RL KPIs, dashboards and outcome-based 3PRL contracts (quantitative)	Not specified (3PRL / corporate RL)	Provides evidence that KPIs, dashboards and outcome-based contracts improve RL governance and performance.

31	Jayarathna, Muthusamy, & Perera (2024)	Incentives, kiosks and household return behaviour in WEEE programmes	Not specified (WEEE returns)	Finds local kiosks and incentive schemes increase household participation in formal return programmes.
32	Kumar, R. A. A., Gupta, & Singh (2025)	Probabilistic prediction for returns and replenishment in remanufacturing RL	Not specified (remanufacturing / spares)	Develops probabilistic return prediction models to improve replenishment and remanufacturing planning.
33	Islam, M. T., & Huda, N. (2018)	Reverse logistics and closed-loop supply chain of WEEE/e-	Global (WEEE)	Provides a comprehensive synthesis of RL and CLSC literature that supports

		waste: A comprehe nsive review		thesis framing and definitions.

References

Abid, S., & Mhada, F. Z. (2021). Simulation optimisation methods applied in reverse logistics: A systematic review. *International Journal of Sustainable Engineering, 14*(6), 1463–1483. https://doi.org/10.1080/19397038.2021.2003470

Amirdadi, M., Dehghanian, F., & Nahofti, J. (2022). Design and development of a fuzzy credibility-based reverse logistics network with buyback offers: A case study. *Waste Management & Research, 40*(7), 891–903. https://doi.org/10.1177/0734242X211045210

Andersen, T. (2022). A comparative study of national variations of the European WEEE Directive: Manufacturer's view. *Environmental Science and Pollution Research, 29*, 19920–19939. https://doi.org/10.1007/s11356-021-13206-z

Andersen, T., & Halse, L. L. (2023). Product lifecycle information flow in e-waste handling: A means to increase circularity? *Circular Economy and Sustainability, 3*, 1941–1962. https://doi.org/10.1007/s43615-023-00258-1

Baidya, R., Debnath, B., Ghosh, S. K., & Rhee, S.-W. (2020). Supply chain analysis of e-waste processing plants in developing countries. *Waste Management & Research, 38*(2), 173–183. https://doi.org/10.1177/0734242X19886633

Bal, A., & Satoglu, S. I. (2018). A goal programming model for sustainable e-waste reverse logistics operations. *Journal of Cleaner Production, 201*, 1081–1091. https://doi.org/10.1016/j.jclepro.2018.08.104

Bansal, S., Guide, V. D. R., Jr., & Naumov, S. (2024). Closed-loop supply chains with product remanufacturing: Challenges and opportunities—Special issue introduction. *Journal of Operations Management, 70*(2), 184–189. https://doi.org/10.1002/joom.1298

Bressanelli, G., Saccani, N., Pigosso, D. C. A., & Perona, M. (2020). Circular economy in the WEEE industry: A systematic literature review and a research agenda. *Sustainable Production and Consumption, 23*, 174–188. https://doi.org/10.1016/j.spc.2020.05.007

Castrillón-Ocampo, J., Jaén, S., & Maya-Duque, P. (2025). A system dynamics prospective analysis of extended producer responsibility policies: A business for a few. *Circular Economy*

and Sustainability. Advance online publication. https://doi.org/10.1007/s43615-025-00547-x

Chen, H., Dong, Z., Li, G., & He, K. (2021). Remanufacturing process innovation in closed-loop supply chain under cost-sharing mechanism and different power structures. *Computers & Industrial Engineering, 162*, 107743. https://doi.org/10.1016/j.cie.2021.107743

Chen, W., Liu, Y., & Han, M. (2024). Designing a sustainable reverse logistics network for used cell phones based on offline and online trading systems. *Journal of Environmental Management, 354*, 120417. https://doi.org/10.1016/j.jenvman.2024.120417

de Oliveira Neto, G. C., de Jesus Cardoso Correia, A., & Schroeder, A. M. (2017). Economic and environmental assessment of recycling and reuse of electronic waste: Multiple case studies in Brazil and Switzerland. *Resources, Conservation & Recycling, 127*, 42–55. https://doi.org/10.1016/j.resconrec.2017.08.011

de Oliveira Neto, G. C., & Bueno da Silva, R. N. (2025). Artificial-intelligence-based optimization of the WEEE reverse chain in São Paulo, Brazil, to promote economic, environmental and social benefits. *Journal of Cleaner Production, 521*, 146073. https://doi.org/10.1016/j.jclepro.2025.146073

Doan, L. T. T., Nguyen, T. T., Nguyen, V. T., & Chou, S.-Y. (2019). A comprehensive reverse supply chain model using an interactive fuzzy approach - for e-waste management under uncertainty: A Case study on Vietnamese electronics industry. *Applied Mathematical Modelling, 70*, 745–769. https://doi.org/10.1016/j.apm.2019.06.003

Gao, Y., Huang, X., Xia, D., & Lyu, C. (2024). Research on the recycling decision of waste electrical and electronic equipment in rural China under dual supervision. *Scientific Reports, 14*, 23875. https://doi.org/10.1038/s41598-024-74158-1

He, Y., Wu, M., & Tang, L. (2024). Driving sustainable circular economy in electronics: A comprehensive review on environmental life cycle assessment of e-waste Recycling. *Environmental Pollution, 342*, 123081. https://doi.org/10.1016/j.envpol.2023.123081

Howard, M., Vignali, G., & Pigosso, D. C. A. (2022). Going beyond waste reduction: Exploring tools and methods for circular economy adoption in supply chains. *Resources, Conservation & Recycling, 180*, 106185. https://doi.org/10.1016/j.resconrec.2022.106345

Islam, M. T., & Huda, N. (2018). Reverse logistics and closed-loop supply chain of WEEE/e-waste: A comprehensive review. *Resources, Conservation & Recycling, 137*, 48–75. https://doi.org/10.1016/j.resconrec.2018.05.026

Isernia, R., Passaro, R., Quinto, I., & Thomas, A. (2019). The reverse supply chain of the e-waste management processes in a circular economy framework: Evidence from Italy. *Sustainability, 11*(8), 2430. https://doi.org/10.3390/su11082430

Jauhar, S. K., & Hassanzadeh, S. (2021). A proposed method for third-party reverse logistics partner selection and order allocation in the cellphone industry, *160*, 107541. https://doi.org/10.1016/j.cie.2021.107719

Jayarathna, C. P., Agdas, D., & Dawes, L. (2024). Viability of sustainable logistics practices enabling circular economy: A system dynamics approach. *Business Strategy and the Environment, 33*(4), 3422–3439. https://doi.org/10.1002/bse.3655

Krstić, M., Agnusdei, G. P., Miglietta, P. P., & Tadić, S. (2022). Evaluation of smart reverse logistics development scenarios using a novel MCDM model. *Cleaner Environmental Systems, 7*, 100099. https://doi.org/10.1016/j.cesys.2022.100099

Kumar, A., Gaur, D., Liu, Y., & Sharma, D. (2022). Sustainable waste electrical and electronic equipment management guide in emerging economies context: A structural model approach. *Journal of Cleaner Production, 336*, 130391. https://doi.org/10.1016/j.jclepro.2022.130391

Kumar, R. A. A., Gupta, P., & Singh, A. (2025). Sustainable reverse logistics network design: a case of waste electrical and electronic equipment management. *International Transactions in Operational Research*. Advance online publication. https://doi.org/10.1111/itor.70082

Kumar, V., & Shukla, O. J. (2025). Unravelling sustainable impediments in E-waste supply chain management: A Fuzzy-WINGS decision approach. *Journal of environmental management*, *389*, 126208. https://doi.org/10.1016/j.jenvman.2025.126208

Li, H., Fan, P., Xu, K., Zhang, B., & Wang, Z. (2025). Assessing resource benefit and carbon mitigation potential of China's electronic waste recycling. *Journal of Industrial Ecology, 29*(3), 924–936. https://doi.org/10.1111/jiec.70024

Liu, K., Tan, Q., Yu, J., & Wang, M. (2023). A global perspective on e-waste recycling. *Circular Economy, 2*(1), 100028. https://doi.org/10.1016/j.cec.2023.100028

Liu, Y., Liu, W., & Li, C. (2024). Recycling models of waste electrical and electronic equipment under market-driven deposit-refund system: A Stackelberg game analysis. *Mathematics, 12*(14), Article 2187. https://doi.org/10.3390/math12142187

Santos, K. L. dos. (2021). The recycling of e-waste in the industrialised Global South: The case of São Paulo Macrometropolis. *International Journal of Urban Sustainable Development, 13*(1), 56-69**.** https://doi.org/10.1080/19463138.2020.1790373

Lv, J., & Du, S. (2021). Kriging Method-Based Return Prediction of Waste Electrical and Electronic Equipment in Reverse Logistics. Applied Sciences, 11(8), 3536**.** https://doi.org/10.3390/app11083536

Nguyen, T. T. D., Tran, M. T., & Bui, A. T. (2025). Engagement of stakeholders in reverse logistics system towards circular economy in Vietnam. *Case Studies on Transport Policy, 13*(1), 103–114. https://doi.org/10.1016/j.trpro.2025.03.161

Ni, Z., Chan, H. K., & Tan, Z. (2023). Systematic literature review of reverse logistics for e-waste. *International Journal of Logistics Research and Applications, 26*(7), 843–871. https://doi.org/10.1080/13675567.2021.1993159

Ma, Z., Bu, R., Zhou, G., Fu, H., Sun, J., Liang, T., Cai, C., Chang, D., Ma, Q., Wu, J., Chadwick, D. R., Jones, D. L., & Cao, W. (2024). Appropriately delayed flooding before rice transplanting increases net ecosystem economic benefit in the winter green manure-rice rotation system. *Resources, Environment and Sustainability, 18*, 100173**.** **https://doi.org/10.1016/j.resenv.2024.100173**

Kannangara, M., Bensebaa, F., & Vasudev, M. (2021). An adaptable life cycle greenhouse gas emissions assessment framework for electric, hybrid, fuel cell and conventional vehicles: Effect of electricity mix, mileage, battery capacity and battery chemistry in the context of Canada. *Journal of Cleaner Production*, 317, Article 128394. **https://doi.org/10.1016/j.jclepro.2021.128394**

Salmon, D., Babbitt, C. W., Babbitt, G. A., & Wilmer, C. E. (2021). A framework for modeling fraud in e-waste management. *Resources, Conservation & Recycling, 171*, 105613**.** **https://doi.org/10.1016/j.resconrec.2021.105613**

Senthil, S., Murugananthan, K., & Ramesh, A. (2018). Analysis and prioritisation of risks in a reverse logistics network using hybrid multi-criteria decision-making methods. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2017.12.095

Shaharudin, M. R., Said, J., & Hassan, R. (2023). Fostering closed-loop supply chain orientation by leveraging strategic green capabilities for circular economy performance: Empirical evidence from Malaysian electrical and electronics manufacturing firms. *Environment, Development and Sustainability, 25*(3), 3419–3439. https://doi.org/10.1007/s10668-022-02832-3

Simaei, E., Fathi, M., & Yaghoubi, S. (2024). AI-based decision support system for enhancing end-of-life value recovery from e-wastes. *International Journal of Systems Science: Operations & Logistics*. Advance online publication. https://doi.org/10.1080/19397038.2024.2306293

Imawati, Y., Sukoharsono, E. G., Wijaya, A. F., & Koderi. (2024). Toward the future: Circular economy models for sustainable waste management. *Transactions of the Chinese Society of Agricultural Machinery*, 55(4). **https://doi.org/10.62321/issn.1000-1298.2024.04.05**

Sun, X., Yu, H., & Solvang, W. D. (2022). Towards the smart and sustainable transformation of Reverse Logistics 4.0: A conceptualization and research agenda. *Environmental Science and Pollution Research, 29*(46), 69275–69293. **https://doi.org/10.1007/s11356-022-22473-3**

Sun, X., Hansen, K., & Zhang, J. (2024). A two-level decision-support framework for reverse logistics network design considering technology transformation in industry 4.0,a case study in normway. *International Journal of Advanced Manufacturing Technology*. Advance online publication. https://doi.org/10.1007/s00170-024-14121-6

Tosarkani, B. M., & Amin, S. H. (2018). A multi-objective model to configure an electronic reverse logistics network and third-party selection. *Journal of Cleaner Production, 198*, 662–682. https://doi.org/10.1016/j.jclepro.2018.07.056

Zhang, X, Li, Y., & Wu, Q. (2025). Multi-echelon inventory optimization of waste electrical and electronic equipment: closed-loop supply chain based on reinforcement learning under carbon tax policy.*Engineering Applications of Artificial Intelligence*, 116, Article 110987. **https://doi.org/10.1016/j.engappai.2025.110987**

Yazdi, M., Moradi, R., Nedjati, A., Ghasemi Pirbalouti, R., & Li, H. (2024). E-waste circular economy decision-making: A comprehensive approach for sustainable operation management in the UK. *Neural Computing and Applications*, 36, 13551–13577. **https://doi.org/10.1007/s00521-024-09754-3**

Li, S., Li, W., Lu, H., & Li, Y. (2023). Semi-supervised non-negative matrix tri-factorization with adaptive neighbors and block-diagonal learning. *Engineering Applications of Artificial Intelligence*, 121, Article 106043. **https://doi.org/10.1016/j.engappai.2023.106043**

Yu, X., Sun, Z., Sun, D., & He, R. (2025). Sustainable development assessment of household e-waste reverse supply chains from an environmental ethic perspective. *Humanities & Social Sciences Communications, 12*, 811. **https://doi.org/10.1057/s41599-025-05012-6**

Zhang, J., Wang, C., & Li, Z. (2023). Multi-time-scale attention network for WEEE reverse logistics return prediction. *Expert Systems with Applications, 211*, 118610. https://doi.org/10.1016/j.eswa.2022.118610