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CIRCULAR LOGISTICS: MODELING REVERSE SUPPLY CHAINS FOR E-WASTE RECOVERY - A REVIEW

NIRERE MARTINE; LI ZHAOLEI; & NABILA CHOUAIB KANTE

Department of Logistics Engineering and Management, Chang'an University, Xi'an China

Corresponding Author: nireremartine@gmail.com

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Abstract

Electronic waste (e-waste) has emerged as one of the fastest-growing waste streams globally, posing severe environmental and health hazards. In response, Circular Logistics, particularly Reverse Supply Chain (RSC) models, have garnered increasing attention for their ability to manage e-waste sustainably. This paper adopts a Systematic Literature Review (SLR) methodology, analyzing 87 peer-reviewed journal articles from databases such as Scopus, IEEE, Web of Science, and ScienceDirect. The review categorizes the existing RSC models into deterministic, stochastic, fuzzy logic, multi-objective, and hybrid approaches. Results indicate that hybrid models are gaining popularity due to their robustness in uncertain environments, while developing countries remain underrepresented in current modeling efforts. Emerging technologies such as AI, IoT, and blockchain are influencing model development. The study identifies significant research gaps and proposes future research directions emphasizing adaptive, empirical, and policy-integrated modeling approaches.

Introduction

The exponential increase in the generation of electronic waste (e-waste) is driven by rapid technological advancements, frequent upgrades, and the obsolescence of electronic devices. According to the Global E-waste Monitor 2020, approximately 53.6 million metric tons of e-waste were generated worldwide in 2019, with projections reaching 74.7 million tons by 2030 (Forti et al., 2020). E-waste contains

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Prof. A.I. Mteiye [MALAWI]

valuable materials such as gold, silver, copper, and rare earth elements, but also harbors toxic substances like lead, mercury, and cadmium, which pose serious health and environmental threats if not managed properly (Ankit et al., 2021).

Circular logistics, which extends the concept of the circular economy, aims to close product lifecycle loops by prioritizing reuse, remanufacturing, and recycling. The role of Reverse Supply Chains (RSCs) is pivotal in this context, as they enable the reverse flow of materials from consumers to manufacturers or recycling centers (Dachan et al., 2023). Recent studies by Govindan et al. (2015) and Agrawal et al. (2016) have incorporated sustainability metrics and uncertainty management into RSC models focused on e-waste recovery (Govindan et al., 2015). For example, Govindan et al. created a multi-criteria decision-making framework that integrates both environmental and economic goals, while Agrawal et al. introduced a stochastic programming model that considers unpredictable e-waste returns and varying recycling costs. (Rohsig Lopez & Legardeur, 2024) has also emphasized the necessity of including social factors and consumer behavior in RSC design. However, despite the abundance of models, there is still a deficiency in comprehensive frameworks that merge operational, environmental, and socio-economic aspects (Chaturvedi, 2024). Moreover, the majority of current research is focused on developed nations, with scant attention given to informal recycling practices that are common in developing areas.

This review paper aims to synthesize and evaluate the state-of-the-art in modeling reverse supply chains for e-waste recovery, with the following objectives:

⇒ Classify the different modeling techniques used in RSC design.
⇒ Analyze trends and identify emerging technologies impacting model development.
⇒ Highlight geographic and methodological research gaps.
⇒ Propose directions for future research with practical implications.

METHODOLOGY

This study follows a systematic literature review (SLR) methodology, a structured process widely adopted in logistics and supply chain research. The methodology includes:

A total of 142 articles were initially retrieved. After screening and removing duplicates, 87 articles were finally reviewed.

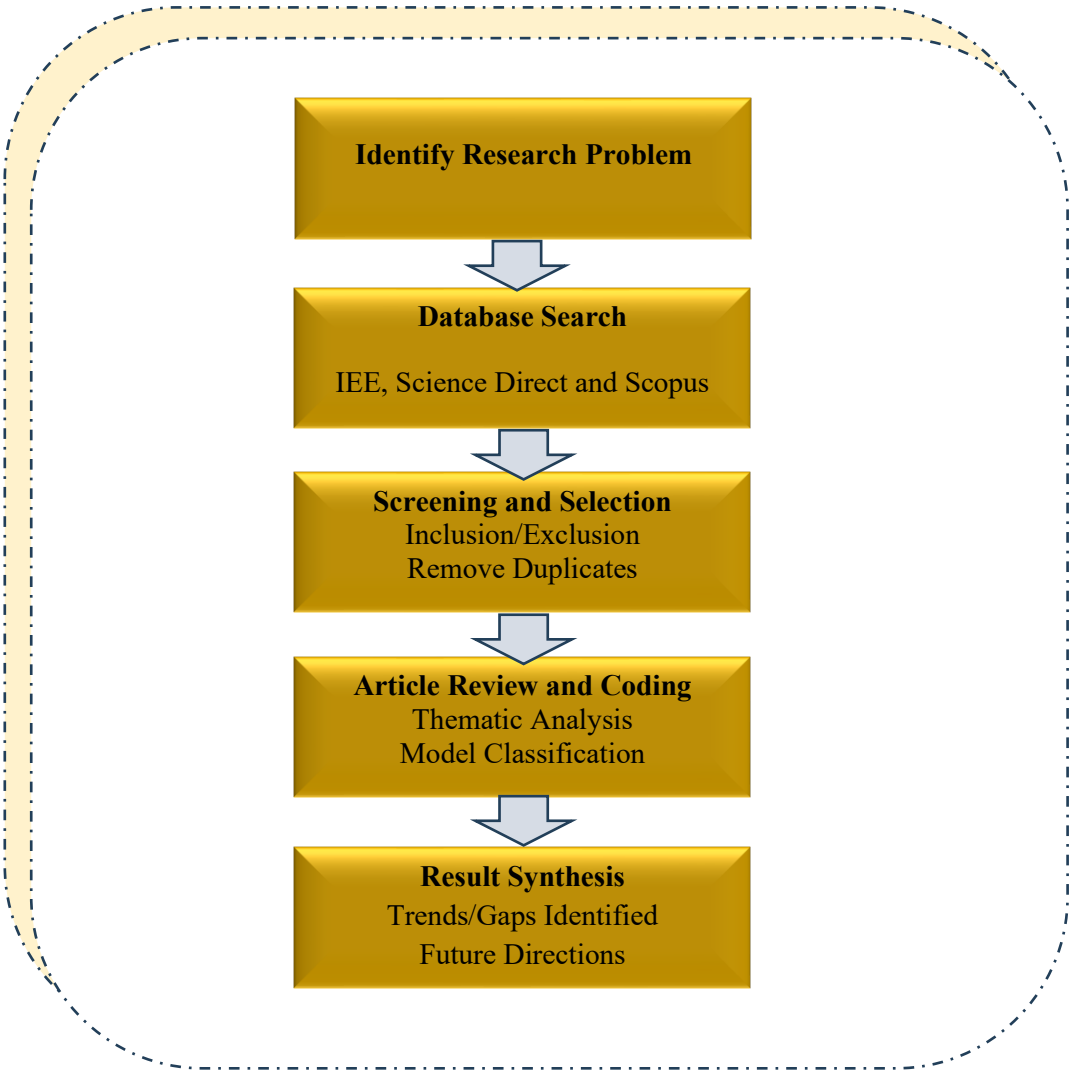


Figure 1: Flowchart of the Research Methodology

CONCEPTUAL FRAMEWORK

This section outlines the theoretical constructs underpinning circular logistics and the reverse supply chain (RSC) for e-waste recovery. The conceptual framework draws on principles from the Circular Economy (CE), Reverse Logistics (RL), and Reverse Supply Chain Management (RSCM), offering an integrated structure to analyze, model, and optimize e-waste flows.

Circular Economy Principles

The circular economy (CE) seeks to redefine growth by decoupling economic activity from the consumption of finite resources. It is built on three main pillars: designing out waste and pollution, keeping products and materials in use, and regenerating natural systems. In the context of e-waste, CE principles are essential to:

⇒ Extend the life cycle of electronic products.
⇒ Encourage reuse, refurbishment, and remanufacturing.
⇒ Promote responsible recycling practices.

Kirchherr et al. (2017) emphasized that CE extends beyond recycling to encompass a systemic shift toward sustainable resource management across all life cycle stages.

Reverse Logistics (RL)

Reverse logistics refers to the management of products and materials after the point of sale, aiming to recapture value and ensure proper disposal. Key activities include:

⇒ Product returns and warranty recovery.
⇒ Disassembly and material separation.
⇒ Reverse distribution network design.

Rogers and Tibben-Lembke (1999) defined RL as the process of planning, implementing, and controlling the efficient flow of goods and information from the point of consumption back to the origin for value recovery or disposal.

Reverse Supply Chain Management (RSCM)

RSCM extends RL by encompassing end-to-end coordination of actors, resources, and processes across the return and recovery network. Fleischmann et al. (2000) described RSCM as a strategic tool involving design, operation, and control of logistics networks used to collect used products and reintroduce them into the supply chain.

Critical elements of RSCM include:

➢ Stakeholder collaboration (manufacturers, recyclers, retailers).
➢ Multi-echelon facility planning.
➢ Risk and cost trade-off management.

Modeling Techniques in Circular Logistics

Effective circular logistics systems for e-waste recovery require robust decision-making tools. Modeling approaches such as deterministic optimization, stochastic programming, fuzzy logic, and hybrid models enable planners to:

⇒ Identify optimal collection and recycling locations.
⇒ Evaluate uncertainties in supply and demand.
⇒ Balance environmental and economic objectives.

These models integrate CE and RSCM principles into actionable strategies.

Flowchart of the Conceptual Framework

Below is a simplified flowchart illustrating how CE, RL, and RSCM interact to support decision modeling in circular logistics for e-waste:

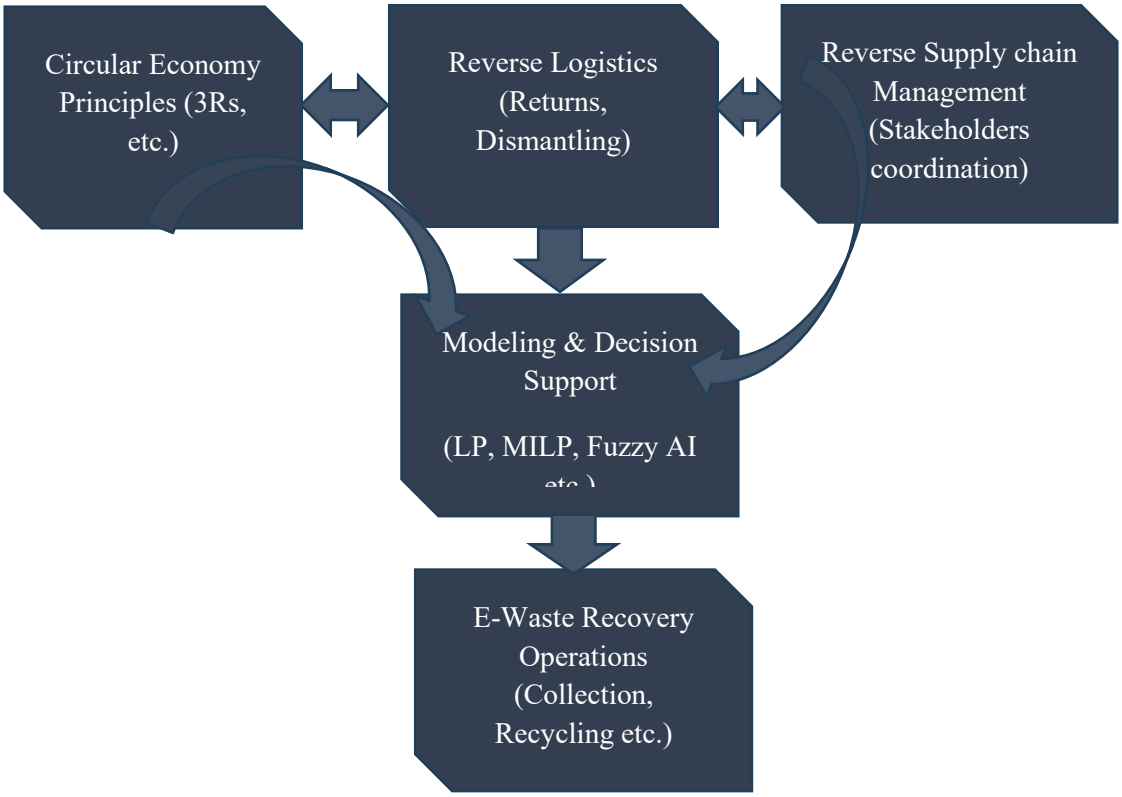


Figure 2: flowchart illustrating how CE, RL, and RSCM interact to support decision modeling in circular logistics for e-waste

APPLICATION TO REVIEW SCOPE

This conceptual framework guides the classification of modeling techniques and recovery activities throughout the review. It helps:

⇒ Link strategic goals (e.g., sustainability) with operational practices (e.g., routing).
⇒ Identify research gaps, such as the lack of behavioral modeling or policy integration.
⇒ Structure comparative analysis of approaches used in different geographic and economic contexts.

This framework enables a comprehensive understanding of the dynamics, tools, and actors involved in circular logistics and e-waste RSCs.

CLASSIFICATION OF RSC MODELS FOR E-WASTE RECOVERY

This section categorizes and analyzes the various modeling approaches used in the design and management of reverse supply chains for e-waste recovery.

Deterministic Models These models assume known parameters such as fixed demand, costs, and return rates. Common techniques include linear programming (LP), mixed-integer linear programming (MILP), and goal programming. They are suitable for well-structured environments.

Stochastic Models These models incorporate randomness and uncertainty in returns, demand, and processing times. Techniques include stochastic programming, Monte Carlo simulations, and probabilistic network analysis.

Fuzzy Logic-Based Models Used to handle vagueness in expert decision-making, especially where numerical data is scarce. Common applications include site selection, supplier evaluation, and customer behavior modeling.

Multi-Objective Optimization Models These models balance conflicting goals such as cost, emissions, lead time, and customer satisfaction. Techniques include genetic algorithms, Pareto-front analysis, and goal programming.

Hybrid Models Combining two or more modeling techniques, hybrid models offer robust solutions that consider uncertainty, imprecision, and multiple objectives simultaneously.

Model Type	Advantages	Limitations	Key References
Deterministic	Simple, structured, efficient	Poor handling of uncertainty	(Srivastava & Balomajumder, 2008), Zhang et al. (2013)
Stochastic	Captures randomness and risk	Complex, computationally intensive	(Agrawal et al., 2019), Li et al. (2019)
Fuzzy Logic	Handles ambiguity in data	Requires expert input	(Govindan et al., 2015), Tseng et al. (2020)
Multi-Objective	Balances trade-offs	Difficult to compare Pareto fronts	Naderi et al. (2018), Fan et al. (2021)
Hybrid	Flexible and adaptive	High modeling and computation cost	(Kazançoğlu et al., 2020), Sahyouni et al. (2021)

5. E-Waste Recovery Activities in Reverse Supply Chains

Activity	Description	Tools/Models Used	Example Work
Collection	Gathering e-waste from consumers	GIS, route optimization	(Govindan et al., 2015)
Transportation	Moving e-waste to recovery centers	VRP, MILP	Li & Tian (2017)
Dismantling	Disassembly of products	Time-motion analysis	Zhang et al. (2016)
Sorting	Classifying components based on condition	Machine learning, fuzzy logic	Tseng et al. (2020)

Activity	Description	Tools/Models Used	Example Work
Refurbishing	Repairing and upgrading old electronics	Cost-benefit analysis	(Sahyouni et al., 2021)
Recycling	Extracting raw materials	Life-cycle analysis (LCA)	(Kazançoğlu et al., 2020)

RESULT AND DISCUSSION

The review of 87 studies highlights several key trends shaping current research in the field. One prominent observation is the growing preference for hybrid models, which are increasingly adopted due to their ability to address multiple objectives simultaneously while effectively managing data uncertainties. Geographically, Asia and Europe stand out as the most prolific regions regarding research output, accounting for the majority of publications. Conversely, Africa and South America are notably underrepresented, highlighting a regional disparity that underscores the necessity for more inclusive global research initiatives. In terms of methodological approaches, optimization-based models continue to prevail in the literature. Nevertheless, there is a significant and swift increase in the utilization of machine learning and artificial intelligence techniques, especially in applications related to sorting processes and predictive tasks. Within recovery activities, operations such as collection and transportation have been the main focus of optimization efforts, while other areas like refurbishing and the modeling of consumer behavior are still in the nascent stages of exploration. These observations indicate both the advancement of certain fields and the emerging prospects for further research in less-developed domains.

Key Insights

⇒ Only 6% of studies included behavioral factors like consumer willingness to return e-waste.

⇒ Less than 10% of models were validated using real-world data or pilot implementations.

⇒ Less than 15% of studies focused on informal e-waste economies, which dominate in several developing countries.

RECOMMENDATIONS AND FUTURE RESEARCH DIRECTIONS

To tackle the identified deficiencies and improve the efficiency of reverse logistics and recovery systems, several essential recommendations and future research avenues are suggested. Firstly, there is an urgent requirement to create regional frameworks that are specifically designed to address the distinct challenges faced by emerging economies, especially those with informal sectors and inadequate infrastructure. These tailored

models would more accurately represent local conditions and enhance practical applicability. Secondly, future research should emphasize empirical validation by utilizing real-world datasets, involving stakeholders for their insights, and performing pilot tests to evaluate model performance in genuine operational settings. Furthermore, the incorporation of advanced technologies such as Artificial Intelligence (AI) and the Internet of Things (IoT) is strongly advised. Innovations like smart bins, predictive maintenance, and automated tracking systems can greatly improve system responsiveness and efficiency. Another significant area for future investigation is behavioral modeling, concentrating on understanding consumer attitudes and motivations regarding the return of used devices.

Utilizing insights derived from behavioral economics alongside organized survey data can lead to the development of more effective incentive strategies. In addition, sustainability metrics ought to be broadened beyond mere economic performance to encompass social impacts, carbon footprints, and energy consumption, thereby facilitating a more comprehensive assessment of recovery systems. Ultimately, research should progressively integrate dynamic policy mechanisms, including taxes, subsidies, and extended producer responsibility (EPR) schemes, into optimization frameworks to enhance support for adaptive, policy-driven decision-making.

CONCLUSION

This review has conducted a critical analysis of the existing research landscape concerning circular logistics, focusing specifically on the modeling of reverse supply chains (RSC) for the recovery of electronic waste (e-waste). By synthesizing findings from 87 peer-reviewed studies that employ a variety of methodologies and span different geographic contexts, the study offers significant insights into the evolution of modeling techniques aimed at supporting circular economy (CE) objectives. It highlights a distinct shift from conventional deterministic models to more sophisticated and flexible frameworks—such as hybrid methods and AI-integrated solutions—that adeptly handle multiple objectives and tackle uncertainty in practical applications. Noteworthy advancements in modeling, including fuzzy logic, stochastic programming, and multi-objective optimization, have greatly enhanced the adaptability and efficiency of reverse logistics systems. Nevertheless, despite these progressions, there are still considerable research gaps—most notably the insufficient integration of behavioral and socio-cultural factors in model design, which are essential for effective implementation and alignment with policy.

REFERENCES

Agrawal, A., Gans, J., & Goldfarb, A. (2019). Exploring the Impact of Artificial Intelligence: Prediction versus Judgment. *Information Economics and Policy*, *47*. https://doi.org/10.1016/j.infoecopol.2019.05.001

Ankit, Saha, L., Kumar, V., Tiwari, J., Sweta, Rawat, S., Singh, J., & Bauddh, K. (2021). Electronic waste and their leachates impact on human health and environment: Global ecological threat and management. *Environmental Technology and Innovation*, *24*, 102049. https://doi.org/10.1016/j.eti.2021.102049

Chaturvedi, D. (2024). The Economics of Sustainable Development: Challenges and Solutions. *Educational Administration: Theory and Practice*, *30*, 9061–9067. https://doi.org/10.53555/kuey.v30i5.4497

Dachan, H., Bilgin, S., & Jönköping, S. (2023). *The Reverse Supply Chains of the Fast-Moving Consumer Goods: The Impacts of Product Returns on Reverse Supply Chains in Sweden PROGRAMME OF STUDY: International Logistics and Supply Chain Management* (Issue May).

Forti, V., Baldé, C. P., Kuehr, R., Bel, G., Jinhui, L., Khetriwal, D. S., Linnell, J., Magalini, F., Nnororm, I. C., Onianwa, P., Ott, D., Ramola, A., Silva, U., Stillhart, R., Tillekeratne, D., Van Straalen, V., Wagner, M., & Yamamoto. (2020). The Global E-waste Monitor 2020: Quantities, Flows, and Resources. In *Ensure healthy Lives and Promote Well-being for All. Experiences of Community Health, Hygiene, Sanitation and Nutrition*.

Govindan, K., Soleimani, H., & Kannan, D. (2015). Reverse logistics and closed-loop supply chain: A comprehensive review to explore the future. *European Journal of Operational Research*, *240*(3), 603–626. https://doi.org/10.1016/j.ejor.2014.07.012

Kazançoğlu, İ., Kazançoğlu, Y., Yarimoglu, E., & Kahraman, A. (2020). A conceptual framework for barriers of circular supply chains for sustainability in the textile industry. *Sustainable Development*, *28*, 1477–1492. https://doi.org/10.1002/sd.2100

Rohsig Lopez, N. S., & Legardeur, J. (2024). Consumer behaviour in the context of circular economy: a systematic literature review. *Proceedings of the Design Society*, *4*, 1417–1426. https://doi.org/10.1017/pds.2024.144

Sahyouni, A., A. A. Zaid, M., & Adib, M. (2021). Bank soundness and liquidity creation. *EuroMed Journal of Business*, *ahead-of-print*. https://doi.org/10.1108/EMJB-04-2019-0061

Srivastava, N., & Balomajumder, C. (2008). Novel biofiltration methods for the treatment of heavy metals from industrial wastewater. *Journal of Hazardous Materials*, *151*, 1–8. https://doi.org/10.1016/j.jhazmat.2007.09.101