Closed-loop and circular supply chains: a meta-review of reverse logistics, product lifecycle and zero-waste strategies

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Abstract

Purpose – The primary aim of this meta-review was to integrate academic research on closed-loop and circular supply chains by examining the links between reverse logistics (RL), product lifecycle management (PLM) and zero-waste strategies. A secondary objective was to demonstrate how sustainability and resource efficiency in supply chain systems are enhanced by combining these elements.

Design/methodology/approach – A systematic literature review was conducted following the PRISMA guidelines that involved screening 102 articles retrieved from six primary databases between 2012 and 2025. Following the application of strict inclusion and exclusion criteria, the initial pool of studies was refined and 24 high-quality studies were retained for analysis. Analysis was then performed to detect significant patterns, trends, or gaps in the research.

Findings – At an operational level, RL facilitates product recovery and waste reduction, PLM offers design and strategic oversight, and zero-waste strategies generate standardised sustainability targets. In combination, they form regenerative supply systems. The notable trends observed were digital technologies, circular product design and the development of regulatory frameworks.

Practical implications – For policymakers and supply chain managers, the review provides actionable proposals by endorsing integrative strategies that ingrain circular principles into logistics and product design processes.

Originality/value – The study proposes an integrated conceptual framework that explains how reverse logistics, product lifecycle management and zero-waste strategies interact through feedback and optimisation mechanisms to enable closed-loop and circular supply chains.

Keywords Closed-loop supply chains, Circular economy, Reverse logistics, Product lifecycle management, Zero-waste strategies, Sustainability, Circular supply chains, Supply chain management

Paper type Literature review

1. Introduction

Faced with limited resources, mounting environmental degradation and the escalating threat of climate change, industries worldwide are being driven by the imperative of sustainability to fundamentally reassess their operational models (Toromade *et al*., 2024). A method that addresses these issues has recently emerged: circular supply chains (Agyabeng-Mensah *et al*., 2024). In contrast to standard linear supply chains, where materials move in accordance with a "take, make, dispose" model, circular supply chains close the loop by ensuring materials are in constant use. Sustainability can thus be enhanced by focusing on efficient use of resources, minimising waste, and mitigating impacts on the environment across product lifecycles (Yang *et al*., 2023).

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Closed-loop supply chains (CLSC) are the components of circular supply chains (Mishra *et al*., 2023a, b). According to these systems, after the conclusion of the lifecycle of a product or material, it can be included again in the system of production after collection, reuse, refurbishment, remanufacturing or recycling. Consequently, there is less consumption of the raw materials and less environmental damage. The shift from linear to circular supply chains is a broader sustainability movement in supply chain operations where economic development is attainable without adversely affecting the environment. It is now a consensus that circular supply chains can create economic value by minimising waste (Zils *et al*., 2025). Furthermore, the implementation of circular supply chain principles by enterprises has become more vital in the face of rigorous environmental policies, as this approach can result in products with extended lifespans. As such, most companies in retailing, manufacturing and logistics industries are now implementing RL, PLM and zero-waste strategies that help enhance the circular flow of materials and information (Gaur *et al*., 2022; Sunmola, 2017). Considering the inherent complexities of circular supply chains, there is a need to emphasise these basic building blocks.

Firstly, the fundamental concept of RL is that users have the ability to channel products back into the supply chain once they have reached the end of their lifecycle. This allows for the recovery of costly resources and minimises waste, in addition to enabling suitable recycling or waste management. RL plays a vital role in CLSC since it enables the return of products and materials into the production systems. Thus, in circular supply chains, products are designed considering their end-of-life (EOL) stage. By planning for product recovery, remanufacturing or recycling, companies can ensure products are kept within the supply chain for the longest time possible. Thirdly, zero-waste strategies seek to completely eradicate waste by redesigning processes and systems so that every single product and material is reused or recycled. Closed-loop processes support this endeavour by ensuring all materials or products are either repurposed or reintroduced into the supply chain, keeping the environmental impact to a bare minimum. By striving for waste reduction at each stage of the supply chain, the zero-waste approach supplements the objectives of circular supply chains. Each of the three elements detailed above assists in pursuing the wider aim of creating a circular economy (CE), through the continuous reuse and regeneration of products and materials, resulting in a sustainable business model that meets environmental standards.

Although research on the individual elements of circular supply chains has been extensive, no study to date has organised these components into an overarching framework. However, addressing these elements in isolation offers little insight into the ways in which they interconnect and how they contribute collectively to the circular supply chain model. Furthermore, studies have yet to consider how these elements can be integrated within the broader supply chain, in particular regarding how they can be implemented across various industries. In brief, although the potential of circular supply chains to limit waste and promote sustainability is being increasingly recognised, there is no unitary position within the extant literature concerning how these components operate in tandem. Although the research in this field is growing, there are still many gaps to be filled. First, there is no coherent explanation of how reverse logistics, product lifecycle and zero-waste operations work together in terms of a single system in a linear with closed-loop or circular supply chain. The majority of studies address these aspects in isolation and provide a limited illustration of their collective influence. Second, there is a lack of an overarching systemic-level framework in the existing literature that outlines how operational activities (e.g. reverse logistics), design-oriented decisions (e.g. lifecycle management) and sustainability targets (e.g. zero waste) relate to each other. Feedback loops and such continuous improvement across the supply chain are neglected, for example. And, third, many studies do not even take the step of translating their findings into practical guidance. Managers and policy makers are seldom provided with any concrete guidance to put these ideas into practice in real industrial settings, particularly across sectors. Consequently, while circular supply chains are generally acknowledged as being important, there is a lack of a common understanding of how their main elements operate in combination in practice.

To fill these gaps, this meta-review aims to answer the following research questions:

RQ1. How is the role of reverse logistics, product lifecycle management and zero-waste strategies described in literature in closed-loop and circular supply chains?

RQ2. In what ways do reverse logistics, product lifecycle management and zero waste strategy support and reinforce each other in achieving enhanced performance of circular supply chain approach?

RQ3. How can reverse logistics, product lifecycle management and zero-waste strategies be integrated into an overarching conceptual framework to account for the performance of a CLSC network system and its sustainability aspects?

Theoretically as well as practically, this study provides significant contributions in circular supply chain domain. This study adds to the body of knowledge by combining reverse logistics, product lifecycle management and zero waste strategy into an integrated framework. As such, one of the main contributions of this article is that it develops an integrated conceptual framework that integrates RL and PLM in addition to zero-waste strategies in circular supply chains. Rather than considering these components in isolation, the article details how they function as a whole. This aids in explaining the relationships between operational activities, design decisions and sustainability targets through feedback and learning. For a practical perspective, this research provides substantive recommendations for managers, designers and policymakers. The model facilitates determining where focus for improvement can be addressed, through material recovery and product design and waste reduction. Thereby, it facilitates successful and more realistic deployment of closed-loop supply chains in various sectors.

Concentrating on theoretical insights as well as practical implications, this article is structured as follows: Section 2: Literature Review presents a synopsis of the theoretical bases and core concepts of both closed-loop and circular supply chains, reviews research on RL, PLM and zero-waste strategies, and makes important links between these components. Section 3: Methodology details the research methodology utilised in the meta-review, specifies the criteria for choosing relevant studies, outlines the search strategy and describes the process of data analysis. Section 4: Conceptual Framework describes the integrated framework that links RL, PLM and zero-waste strategies within the circular supply chain. Section 5: Discussion critically evaluates the findings, examines the implications for businesses and policymakers, identifies gaps in the literature and proposes directions for future research. Lastly, Section 6: Conclusion provides an overview of the main insights and provides recommendations as to how circular supply chain practices can be integrated into different industries.

2. Literature review

2.1 RL and its role in circular supply chains

RL is defined as managing the return of products from the point at which they are consumed to the point of origin or another location so that they can be recovered, reused, recycled, remanufactured or disposed of (Hanafi *et al*., 2008). In contrast to traditional forward logistics, where goods move in one direction only, RL concerns the reverse flow of goods. It is fundamental to circular supply chains, where the aim is to form a closed-loop system under which products, materials and resources are continuously reused or refurbished, reducing waste and the requirement for raw materials while increasing the sustainability of production processes. This contrasts with linear supply chains, where products are typically discarded at the point where they are no longer useful (Mishra *et al*., 2023a, b; Roy *et al*., 2022). RL thus functions as a core mechanism for the recovery of products. Once such products have reached the end of their lifecycle, they are collected and then subjected to either a process of refurbishment or remanufacturing to produce new goods or raw materials. Consequently, RL enables the development of a business model that aligns with CE objectives.

The literature contains multiple theoretical frameworks that promote the use of RL within the CE, highlighting the valuable role it plays in supporting sustainable development. These include CLSC models, Sustainable Supply Chain Management (SSCM) and Industrial Ecology (Belhadi *et al*., 2022; Elfarouk *et al*., 2023). To avoid products going to waste after they have reached the end of their useful lives, CLSC models help accommodate cyclical material and facilitate product movement through the system (Zarreh *et al*., 2024). SSCM encourages the integration of sustainability principles into operational methods to improve supply chain environmental, economic and social performance (Le *et al*., 2022; Liu *et al*., 2023). Industrial Ecology promotes business sustainability by emphasising maximising resource utilisation, waste production reduction and greener activities (Al-Thani and Al-Ansari, 2021; Awan, 2022). CE principles are also key to other models, including resource recovery, remanufacturing and product-as-a-service models, in which RL is commonly utilised, thus allowing products to be returned, reused, refurbished and redistributed. Through such activities, businesses get extra value out of retired products, contributing to the fight against climate change and achieving SDG-13 by eliminating the need to develop new production methods and reducing carbon emissions (Luo *et al*., 2025). RL also supports the goal of SDG-6 (maintaining a healthy and clean environment) because it conserves both energy and water (Arora and Mishra, 2022; Borowski, 2024).

In the contemporary business environment, RL systems are becoming ever more crucial and fundamental owing to intertwined issues such as legal requirements, corporate social responsibility (CSR) and customer expectations (Adesoga *et al*., 2024). RL can be particularly advantageous for businesses when trying to achieve a competitive edge. Van Wassenhove and Guide (2009) and Charnley *et al*. (2024) stated that, despite their significantly high value, numerous items returned by consumers to stores are neither processed nor recovered. Hence, RL can reduce material input costs, minimise risks linked with price fluctuations and disruptions to supply chains (Gaustad *et al*., 2018; Wilson and Goffnett, 2022; Pan *et al*., 2025) and create new revenue streams by enabling products to be remanufactured or recycled (Larsen and Jacobsen, 2016). This offers businesses critical financial benefits in India (Chebrolu and Dutta, 2021). In developing economies such as India, which is experiencing considerable environmental problems and increasing consumer demand, the implementation of RL is essential to achieving long-term sustainability goals.

However, major barriers to the introduction of RL continue to be linked to infrastructure, regulatory frameworks and the need to adopt sustainable business practices. Collaborative efforts among businesses, consumers and governments are required to develop the systems, incentives and policies needed to support RL. Nevertheless, research on the economic, social and environmental impacts of RL systems is continually evolving, creating new opportunities for businesses to reduce costs, enhance sustainability and enhance their competitive position in the market. Businesses that utilise RL effectively will become less dependent on new raw materials, reduce waste and contribute to building a more sustainable international economy (Fernando *et al*., 2023). Moreover, further integrating RL into circular supply chains will promote pioneering business models, generate new economic opportunities and assist in achieving critical environmental targets. Hence, whether CE initiatives succeed in increasing sustainability in international supply chains is therefore contingent on the continuing development of RL practices.

The challenges RL faces within a CE are, however, numerous. Arguably most salient is the lack of any return strategic plans, often leading to ineffective processing of waste due to lost returns, high costs, and missed opportunities for reusing or recycling goods. Corporations very often fail to implement integrated strategies that streamline the process of returns and improve product reuse (Sonar *et al*., 2024). This issue is particularly evident in the consumer goods and electronics industries because RL is constrained by inadequate infrastructure. The second major barrier is a lack of clarity regarding the demand for returned products. Therefore, it is difficult for companies to estimate the amount of goods that will be returned, and at what percentage. Moreover, it is challenging to sort out stock and to determine how goods will be reused or resold. This adversely impacts the efficiency and profitability of operations, particularly in the retail and e-commerce business sectors, where returns are necessary to maintain customer satisfaction, though they create financial issues (Sonar *et al.*, 2024; Lamba *et al.*, 2020). A third challenge lies in regulatory uncertainty, especially in emerging economies where recycling laws and waste disposal regulations are insufficient or non-existent. This results in inefficient RL practices, which limit the extent to which RL can meaningfully contribute to both sustainability and the CE (Ohiomah and Sukdeo, 2022).

2.2 Product lifecycle management and its role in circular supply chains

PLM covers all stages of a product's lifecycle, from development and design to eventual recycling or final disposal (Stark, 2022). Hence, it results in less environmental degradation, maximises use of resources and promotes greater sustainability. For this reason, PLM is critical in ensuring products meet one of the key principles of PL – they must be capable of being disassembled, reused and recycled. Whilst larger quantities of waste and environmental degradation are produced by the linear "take, make, dispose" model, the use of PLM in circular supply chains ensures that EOL phases of products are considered, in order to rely less on raw materials and to eliminate or cut waste through reuse, disassembly for remanufacturing, or recycling.

PLM offers several advantages in closed-loop supply chains, such as minimising waste and maximising the use of resources. Design for reuse or remanufacturing or recycling reduces dependency on raw materials. In addition to preserving natural resources, it lessens environmental damage caused by extraction, production or waste disposal activities. An uninterrupted loop whereby materials are recycled continuously through supply chains enables organisations to rely less on raw materials, thus making such activities less expensive, given that raw materials tend to be extremely costly, particularly in some industries (Ketchen and Hult, 2007). Additionally, revenue streams from fresh sales of reused or remanufactured products give organisations a competitive edge over their counterparts in industries where customers are strongly passionate about environmental responsibility issues (Shmelev and Gilardi, 2025). Furthermore, an organisation is more likely to enhance its brand image if its products align with ideals of circularity and environmental responsibility, because such products will appeal to eco-conscious customers and investors. A second key benefit for PLM in closed-loop supply chains lies in the fact that it facilitates waste management and compliance with regulatory demands for sustainability. As environmental regulations established by governments worldwide become stricter, PLM will enable organisations to address recycling, remanufacturing, and waste minimisation requirements for their products. Similarly, it will allow them to address United Nations Sustainable Development Goals, which target waste reduction minimisation, resource conservation and climate change mitigation. With the implementation of PLM practices, organisations are capable of being market leaders in environmental responsibility, which enables them to transition into new industries and enhance their credibility amongst customers, regulators and various other stakeholders (da Silva and Sehnem, 2025).

Although it holds enormous promise, many enduring issues hinder the full deployment of PLM across circular supply chains. One of the most serious issues is that, to ensure products can be disassembled, repaired or recycled, they will have to undergo substantial redesigning which will require enormous investments in research and development (R&D), advanced production technologies and supply chain changes (Zhang *et al.*, 2023). For most organisations, particularly small- and medium-sized enterprises (SMEs), the costs associated with the initial implementation of PLM are prohibitive. A second problem is that design practices, recycling practices and product manufacturing lack standardisation across differing industries and geographical locations. Consequently, the adoption of PLM by businesses can be extremely challenging. Moreover, for multinational companies operating in different regulatory environments, the inconsistency of national regulations hinders them from adopting circular practices (Lai and Hung, 2024). Lastly, companies frequently need to undergo a cultural shift to integrate PLM into circular supply chains, transitioning from a linear to a circular mindset. This necessitates collaboration between design, production, logistics and marketing departments, and resistance may be encountered from stakeholders who favour traditional working methods (Badwan, 2025).

2.3 Zero-waste strategies in circular supply chains

Zero-waste strategies form a core component of the CE, as they facilitate the transformation of traditional linear supply chains into sustainable, closed-loop systems. Their principal objective is to completely eradicate waste by designing systems that prioritise the reuse, recycling, and recovery of all materials at every stage of the product lifecycle. The integration of zero-waste principles within circular and closed-loop supply chains means that waste is not simply managed; it is also tactically designed out of the system (Shaharudin *et al*., 2023).

To successfully apply a comprehensive zero-waste strategy requires a systemic transformation that involves much more than simple consumer recycling (Almansour and Akrami, 2024). It commences at the design stage, where product ideas are developed with consideration given to their full lifecycle. In this regard, an extremely important principle is design for disassembly (DfD), which means it is easy to dismantle products upon completion of their useful lives, a process that enables components to be reused, separates materials and promotes efficient recycling. Simplifying disassembly allows businesses to considerably reduce the effect on the environment of manufacturing complicated and mixed-material products. A useful example of this can be found in the electronics industry, where the implementation of modular design enables manufacturers to extract high-value components (such as chips or batteries) prior to recycling whatever remains, reducing electronic waste and maximising recovery value.

The production of waste at source can be curtailed through the adoption of zero-waste strategies. Methods of achieving this include the use of by-products from industrial processes, optimisation of production to limit material offcuts and enhancement of packaging (Jain *et al*., 2024). The effectiveness of such an approach will be boosted in circular supply chains that incorporate closed-loop quality management systems, LCAs, and streamlined manufacturing practices. For instance, the practice of reprocessing and remanufacturing loops, through which it is feasible to feed materials back into the production process via minimum use of energy, is being increasingly adopted by businesses. Therefore, it is viable to reduce raw material use and support both efficient resource use and economic circularity.

To increase the effectiveness of zero-waste initiatives across supply chains, coordination is required among suppliers, producers and distributors in meeting the needs of customers (Mishra *et al*., 2025). Additionally, IT tools such as enterprise resource planning (ERP) and blockchain-activated tracking platforms could be employed for open monitoring and tracking of material flows in order to avoid waste or create value. For this reason, suppliers will have to be incentivised to supply biodegradable, recyclable or renewable materials, and supply-chain logistics partners will have to facilitate reverse flows and material consolidation.

Significant economic and environmental benefits are achievable when introducing zero-waste strategies to CLSCs, given that they reduce both carbon emissions and landfill dependency, as well as support regulatory compliance with emerging EPR frameworks (Bogusz *et al*., 2021). Simultaneously, these strategies create opportunities for innovation in product and process design, and open new revenue streams through secondary material markets.

It is therefore clear that, instead of isolated efforts towards achieving sustainability, zero-waste strategies are the core design and operational principles within circular supply chains. Strategies such as design for disassembly, waste minimisation and the strategic recovery of materials are driving the shift towards resource-efficient and regenerative supply networks. However, they can only be implemented successfully if the supply chain architecture undergoes a holistic redesign, supported by stakeholder collaboration, technological integration and a long-term vision of sustainability.

3. Methodology

3.1 Review protocol and framework

The review protocol and framework outlined in this section are consistent with accepted best practices for systematic literature reviews (Alsadi *et al.*, 2025; Cooper *et al.*, 2018; Gupta *et al.*, 2018; Ng and De Colombani, 2015; Yemini *et al.*, 2025). The protocol was constructed to enable the identification of peer-reviewed articles that evaluate the role that CLSC performs in pursuing sustainability and resource effectiveness. Examining how RL, PLM and waste management strategies are interlinked necessitates a comprehensive discussion of how ideas related to the CE are utilised across distinct industries, with special reference to the ever-changing methodologies advancing the effort towards zero waste. The review time horizon between 2012 and 2025 was chosen as this span includes the most recent developments in circular and closed-loop supply chains, which is consistent with when the concepts of a circular economy started to receive considerable academic and policy attention.

3.2 Eligibility criteria

Clearly specified eligibility criteria were established to promote both thematic and scientific rigour. The inclusion criteria were as follows: (1) peer-reviewed articles on RL, PLM and zero-waste approaches under the framework of circular and closed-loop supply chains, and (2) articles published between January 2012 and April 2025. Adopting such criteria enabled recent articles to be selected carefully so that they fully encompass the dynamic nature of sustainable supply chain practices.

3.2.1 Inclusion criteria (IA). Table 1 includes the inclusion criteria, which ensured that the chosen articles addressed the convergence among closed-loop and circular supply chains from the perspective of RL, PLM and zero-waste strategies.

3.2.2 Exclusion criteria (EA). To identify and omit studies unsuitable for this meta-review, the exclusion criteria presented in Table 2 were applied. This step meant that the review only concentrated on innovative, forward-looking and relevant studies, addressing the most recent developments and practices with regard to sustainability, circular supply chains and the renewable energy sector.

3.3 Search strategy

To identify all relevant literature, a systematic search was conducted of the following academic databases: Scopus, Web of Science, Google Scholar, ScienceDirect, Taylor & Francis Online

Table 1. Inclusion criteria (IA)

Criterion	Description
IA1	Peer-reviewed journal articles and systematic reviews published between 2012 and 2025
IA2	Explicit focus on CLSCs, CE principles, RL or PLM
IA3	Integration of sustainable practices, resource recovery, recycling or waste reduction strategies within supply chain management
IA4	Focus on zero-waste strategies, including waste minimisation, material reuse or circularity in product design
IA5	Discussion of practical applications, frameworks, or case studies in industrial settings, including manufacturing, retail or logistics

Table 2. Exclusion criteria (EA)

Criterion	Description
EA1	Grey literature, including editorials, blogs, white papers, preprints or unreviewed conference proceedings
EA2	Focus on fossil fuel or non-renewable energy logistics without any direct link to renewable supply chain systems
EA3	No consideration of CLSCs, CEs principles, digital transformation or human-centric supply chain methodologies
EA4	Works relying solely on legacy supply chain management models without considering significant innovation, digital augmentation or sustainability
EA5	Non-English language publications that lack validated translations, thereby ensuring accessibility and consistency
EA6	Publications focused on unrelated sectors (e.g. healthcare, retail, agriculture) unless direct applicability or transferability to CLSCs

and SpringerLink. The selected databases (were chosen due to their broad coverage of high-quality peer-reviewed journals in supply chain management, sustainability and operations research. To specifically concentrate on closed-loop and circular supply chains, Boolean searches were performed using particular keywords and combinations of these. The search string employed was: ("closed-loop supply chain" OR "circular supply chain") AND ("RL" OR "product lifecycle" OR "zero-waste") AND ("product recovery" OR "recycling" OR "remanufacturing" OR "waste management" OR "returns management") AND ("sustainability" OR "lifecycle assessment" OR "design for environment" OR "CE").

3.4 Study selection and screening

For this meta-review, the selection and screening process rigidly adhered to the inclusion and exclusion criteria set out in Tables 1 and 2. Initially, 102 studies were identified. These were imported into Mendeley reference management software for citation management, resulting in 23 duplicate records being removed. Initial manual screening against exclusion criteria EA1 and EA2 was then performed for the remaining 79 studies, resulting in the removal of 44 studies that did not fulfil the basic eligibility requirements. This left 35 studies for full-text evaluation. A comprehensive assessment using criteria EA5 and EA6 led to the elimination of 16 studies that lacked relevance to the primary themes of the review. An additional phase of snowballing using the reference lists of the remaining 19 studies generated 7 other relevant articles. Further manual review and application of the inclusion criteria resulted in the exclusion of 2 studies, leaving a final sample of 24 studies for comprehensive analysis (Figure 1). Together, these studies formed the analytical foundation of this meta-review as they offer a detailed and up-to-date synopsis of the ever-changing landscape of circular and CLSC strategies. The final set of 24 studies was assessed based on relevance, methodological rigor, clarity of contribution and alignment with the objectives of the meta-review.

4. Conceptual integrated framework for CLSCs: interlinking PLM, RL and zero-waste strategies through feedback and optimisation

In this modern era, where innovations are driven by sustainability, closed-loop and circular supply chains are being recognised as transformative frameworks that can counter the urgent problems of resource depletion, overconsumption, and waste accumulation (Kandpal *et al.*, 2024). Unlike the "take-make-dispose" model used in conventional linear supply chains, closed-loop systems reincorporate used resources into the production and consumption cycle in order for materials and products to retain their value for longer. This increases economic efficiency and resilience across industries while offsetting any adverse environmental effects

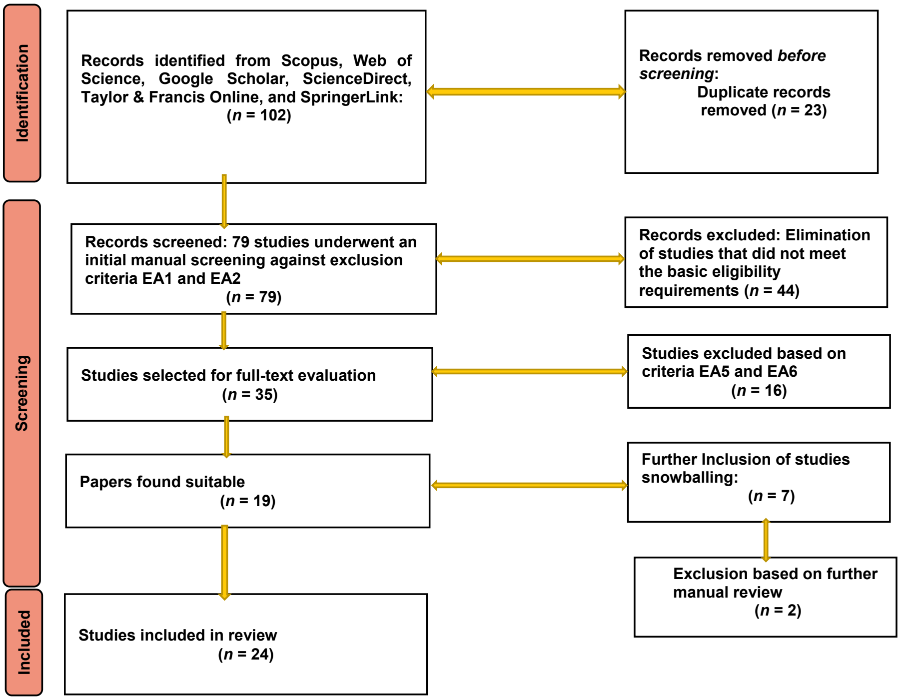

Figure 1. Refinement and inclusion of studies in research process

(Abbas *et al.*, 2025). This conceptual framework necessitates full integration of RL, PLM and zero-waste strategies. This is because these elements are designed to function synergistically rather than in isolation, forming a dynamic and feedback-driven system in which CE principles are entrenched (Raut *et al.*, 2025). As detailed in earlier sections, each element fulfils a distinct set of functions vital to achieving the goals of CLSCs. In a closed-loop system, the operational backbone is provided by RL, the strategic layer comprises PLM, and the desired sustainability goal is achieved through the implementation of zero-waste strategies. These elements motivate companies to divert materials from landfills and design waste out of the system. For this to succeed, businesses need to think systemically as waste in one process will become the input for another. Substitution of materials is also required, with easily recoverable sustainable alternatives replacing non-renewable or toxic materials (Rajendran *et al.*, 2025).

One of the distinct advantages of this conceptual framework is its capacity to facilitate ongoing improvement through the presence of feedback loops (Akram *et al.*, 2023). To clarify, if companies are to improve future product designs, then data created through RL (e.g. product return rates, reasons for failure) needs to be fed into PLM systems. Similarly, the recalibration of logistics and lifecycle strategies will be supported by the use of performance metrics derived from zero-waste strategies. Closed feedback mechanisms such as this result in a supply chain that is more adaptive, intelligent and resilient. Furthermore, the framework will need to support collaboration between manufacturers, consumers, regulators and recyclers with respect to aligning targets, sharing data and devising solutions. This is essential to attaining full circularity. Integrating RL, PLM and zero-waste strategies into a unitary conceptual framework will enable companies to convert their supply chains into regenerative systems aligned with CE principles. In a world where resources are in short supply, this approach will increase operational efficiency and stewardship of the environment while guaranteeing sustained resilience.

This conceptual framework (Figure 2) is extremely important for several interconnected reasons. Firstly, it offers an integrative perspective by combining three distinct yet interlinked elements that are typically treated separately in traditional supply chain analyses. This helps to generate systems-level insights into how operational elements (RL), strategic components (PLM) and normative goals (zero-waste) work in tandem to increase the level of circularity in supply chains.

Secondly, it ensures optimal use of resources. If RL processes are not informed by lifecycle-based design principles, recovery and remanufacturing efforts may be inefficient. Similarly, without strong operational and design strategies, zero-waste objectives amount to nothing more than aspirations. Through the alignment of recovery operations with intelligent product design and sustainable goals, both environmental and economic optimisation are facilitated.

Thirdly, it offers essential support for decision-making among managers, policymakers and sustainability officers. In a sophisticated supply chain environment, transparent and interlinked models are crucial for efficient resource allocation, risk assessment and the identification of high-leverage intervention points. By highlighting feedback gaps, system inefficiencies and design-process misalignments, the framework operates as both a diagnostic and a strategic planning tool.

Fourthly, the framework is premised on feedback-oriented learning. Circular supply chains succeed when embedded with adaptive learning mechanisms. With feedback loops as a central element, the framework focuses on ongoing monitoring, iterative design, and system-wide improvement. For instance, upstream design choices can be informed by insights derived from RL, such as product failure modes or recovery rates, while innovations in zero-waste practices can be driven by LCAs. Finally, there is strong alignment between the framework and international sustainability targets and standards such as SDG 12 (on Responsible Consumption and Production), along with global CE benchmarks promoted by organisations like the Ellen MacArthur Foundation.

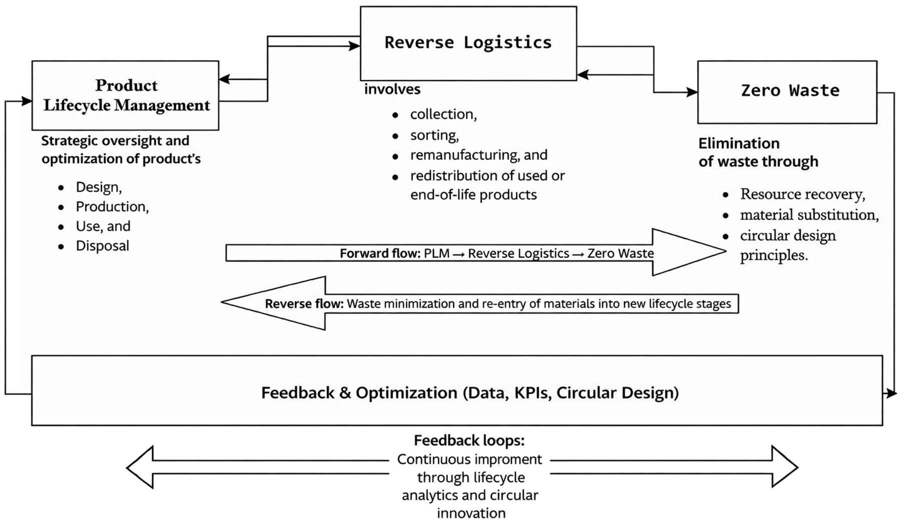

Figure 2. Integrated framework for closed-loop supply chains: interlinking product lifecycle management, reverse logistics and zero-waste strategies through feedback and optimisation. Note: The diagram illustrates how product lifecycle management, reverse logistics and zero-waste strategies are interconnected within a closed-loop supply chain. It highlights continuous feedback and optimisation using data and KPIs, enabling material recovery, waste minimisation and circular design, thereby fostering sustainability and efficiency throughout the supply chain system. Source: Author'

Consequently, the framework is widely applicable and relevant to industrial innovation, academic research and public policy initiatives aimed at creating sustainable as well as regenerative supply chains. In conclusion, the conceptual framework proposed in this article offers a coherent and unified lens through which to understand and operationalise the CE in supply chains. Through the creation of a closed-loop system – driven by feedback and adaptive mechanisms – incorporating RL, PLM and zero-waste strategies, a practical and theoretical framework for assessing the maturity of circular supply chains is offered. Both synergistic and additive, such integration sheds light on the dynamic connections that govern circular transitions within supply networks.

5. Discussion

This systematic meta-review of 24 peer-reviewed studies has comprehensively and coherently explained how RL, PLM and zero-waste strategies interconnect to create the foundation for closed-loop and circular supply chains. These elements strengthen and support each other in attaining holistic sustainability within modern supply chains. Encompassing return management, collection, sorting, remanufacturing and redistribution processes, RL forms the operational backbone of closed-loop systems, enabling used or end-of-life products to physically flow back into the production cycle (Ciliberto *et al.*, 2021). However, the effectiveness of RL is reliant on product design and thus PLM. The strategic role played by the latter is therefore crucial, as its focus on modularity, durability, disassembly, and recoverability ensures products are designed with circularity in mind. The forward thinking this provides means that RL will be cost-effective and easier to implement. Moreover, PLM bridges operational and environmental domains as it assesses the sustainability of a product throughout its lifecycle. On the other hand, the normative direction of circular supply chains is determined by applying zero-waste strategies. These incorporate circularity principles into every process, ensuring full reuse of materials by eliminating landfill-bound waste while optimising resource efficiency. These strategies are operationalised by both design decisions (PLM) and RL capabilities, illuminating the indispensable connections between the three components. Notably, the literature suggests that if companies are able to align these elements successfully, they will achieve greater economic resilience, enhanced material efficiency and exert a markedly smaller environmental impact (Chen *et al.*, 2025; Zhang and Tian, 2024). Thus, it is the synergy among RL, PLM and zero-waste goals that underpins the transition from linear to regenerative supply chain models.

The emergence of various trends is engendering a fundamental transformation in closed-loop and circular supply chains. Firstly, developing technologies are driving a paradigm change in the process of capturing and analysing RL and lifecycle data, particularly Industry 4.0 technologies. Tools such as blockchain, the Internet of Things (IoT), AI, and digital twins enable product returns to be monitored in real time, the ability to predict material flows to be enhanced and smart decision-making in terms of product repair, refurbishment and recycling to be enabled. This renders circularity more scalable, measurable, and economically feasible. Secondly, a notable shift towards servitisation and product-as-a-service (PaaS) models can be seen in business practices. Such practices inevitably promote durability, modular design and post-consumption accountability, all of which align with PLM and RL functions. Businesses are starting to acknowledge that circular supply chains constitute not only a compliance requirement but also a value proposition and competitive advantage. Thirdly, the business case for circular supply chains is being strengthened by policy frameworks and regulatory changes. Initiatives like the EU's Circular Economy Action Plan, EPR mandates and carbon disclosure regulations are compelling companies to embed circularity into their main supply chain strategies. Circular models are also being favoured by public procurement, accelerating the rate of adoption across industries (Karlovsek *et al.*, 2024; Wurster *et al.*, 2021). Collectively, these trends indicate a move from conceptual interest to concrete implementation, supported by technological (Al Saad and Al Talib, 2025; Al-Talib *et al.*, 2025), economic and policy developments.

Nevertheless, although the picture painted is a promising one, there remain a number of gaps in the literature. Firstly, empirical studies validating the success or failure of closed-loop implementations across various industrial sectors are generally lacking. The majority of studies continue to be conceptual or case-based, with few offering cross-sectoral comparisons or quantifiable outcomes. For instance, further exploration is required of comparative LCAs that assess the environmental and economic trade-offs of circular models across different industries. Secondly, few studies have concentrated on the human dimension of circular supply chains. This has resulted in certain issues being overlooked, such as consumer behaviour in product return and reuse systems, workforce reskilling for remanufacturing, and organisational culture change; yet the effective deployment of RL and zero-waste strategies is reliant on comprehending these social dynamics. Thirdly, there has been less focus on integrating circular strategies into low- and middle-income countries. However, the increasing importance of global supply chains means knowledge of how to adapt circular principles to disparate economic, infrastructural and regulatory contexts is essential. Lastly, the interdependencies among PLM, RL and zero-waste strategies within a cohesive analytical framework have not been adequately addressed. Instead, these strategies are often explored in isolation, making a detailed understanding of their joint impact on supply chain performance and sustainability outcomes difficult to achieve.

Although extensive scholarly attention has been given to the theoretical advantages of circular supply chains, businesses must also overcome a number of practical challenges when it comes to implementing them (Ooi *et al*., 2025; Panigrahi *et al*., 2025; Rayhan *et al*., 2025). A major barrier in this regard is that it is both complex and expensive to create an RL infrastructure. To establish systems for collecting, sorting and processing returned goods, a high degree of investment and coordination is required, especially in regions where logistical processes are poorly developed. In addition, inertia regarding product design frequently obstructs progress. Numerous products currently available on the market have not been designed with disassembly or material recovery in mind, rendering the implementation of reverse processes either inefficient or financially unviable. To move to circular design, businesses need a technical redesign while simultaneously overcoming any internal resistance. Another challenge concerns the availability and traceability of data. RL processes may become inefficient or inaccurate without clear information on the composition, usage history and condition of materials, especially for products that have long lifecycles or change hands many times. In addition, it is often difficult to predict the market demand for secondary materials, which constrains the financial feasibility of recovery and reuse systems. Circular models will continue to be economically fragile in the absence of stable end-markets for refurbished goods or recycled inputs. Finally, progress may be hampered by organisational and cultural inertia. Internal champions or aligned incentives to pursue zero-waste goals may be lacking in businesses, particularly when strategic thinking is driven by short-term profit motives.

Drawing on the insights and limitations presented in this meta-review, several encouraging directions for future research can be proposed. First, detailed industry-specific research is required to examine the manifestation of circular strategies across manufacturing, electronics, textiles, automotive and construction sectors. These studies will generate tailored insights and suggest best practices for adoption in various sectors. Secondly, future research should devise and evaluate integrated models that mimic the interactions between RL, PLM and zero-waste strategies across an array of policy, economic, and technological settings. Especially useful in this regard could be agent-based modelling and system dynamics approaches. Thirdly, studies should identify and investigate local innovations and barriers impacting circular supply chains in emerging markets. Studies specific to a particular context will generate insights that are more inclusive and promote the worldwide spread of circularity. Fourthly, there is room to engage in methodological innovation via the real-time integration of data, using tools such as machine learning and the IoT to dynamically track and maximise material flows. To develop supply chain architectures that are adaptive as well as responsive, a combination of digital tools may be required for lifecycle thinking (Ishaq *et al*., 2025; Tanveer *et al*., 2025). Lastly, future research should investigate how collaboration between producers, recyclers, designers, regulators and consumers across value chains can create circular value. Studies on governance models, incentive alignment and stakeholder engagement will be essential in enabling circular supply chains to be scaled.

5.1 Interpretation of findings and theoretical implications

The original contribution is that the effectiveness of circular and closed-loop supply chains does not lie with individual practices as separated activities, but rather within the systemic cross-functionalism between reverse logistics, product lifecycle management and zero-waste. This might be the reason why many previous studies suggest inconsistent or situational outcomes when those components are applied separately. Consistent with previous works highlighting reverse logistics as an operational backbone driving circular supply chains, the current study supports the argument that RL itself is not sufficient to aspire to circularity unless products are designed for recovery and reuse. This is consistent with the earlier conceptual arguments but goes beyond them by showing how PLM becomes a strategic enabler that contextually influences the success factors of RL. Second, findings contribute to the circular supply chain theory by placing zero waste strategies not only as a set of environmental objectives but also as normative drivers that influence design and operation recovery decisions. This systemic explanation goes beyond the usual linear cause–effect explanations commonly found in literature, and is in line with a dynamic (e.g. feedback-based) interpretation of circular supply chains.

5.2 Practical implications

From a practical viewpoint, the results provide a number of key implications for industry and policymakers. The integrated model provides added value to a supply chain manager and clearly indicates that product design decisions should be harmonically balanced with the spectrum of reverse logistics options, right at early stages. Investments in RL infrastructure without lifecycle-based design may lead to high recovery costs and poor sustainability improvements. For policymakers, the results highlight the importance of regulatory regimes that incorporate standards for product design, take-back requirements and waste reduction targets simultaneously. Mechanisms pursuing waste management or recycling alone may not be able to drive circularity without product-specific regulations oriented towards lifecycles. At a sector level, the framework offers organisations a diagnostic tool that can be used to evaluate how companies compare with respect to circular maturity as well as gaps between design, recovery and sustainability objectives.

6. Conclusion, policy implications and limitations

The goal of this study was to provide a synthesis of literature on closed-loop and circular supply chains based on the co-mingled roles of reverse logistics, product lifecycle management and waste elimination. The article applied a systematic meta-review methodology by synthesising findings of 24 high-quality studies and building an integrated theoretical framework to explain how these factors jointly drive sustainability and resource efficiency in supply chain systems. The findings confirm that the intersection of RL, PLM and zero-waste strategies provides a strong foundation upon which to advance sustainable supply chain models. Specifically, RL enables recovery and re-entry of materials into production loops; PLM provides decision-making that is design-centric and lifecycle-informed; and zero-waste strategies ingrain sustainability goals into the operational and normative dimensions of supply chains. Collectively, these strategies merge into dynamic, feedback-oriented systems that pose a robust challenge to the conventional linear "take-make-dispose" paradigm. Moreover, the literature reveals a move towards systemic thinking, where the effectiveness of circular initiatives is impacted by digital technologies, stakeholder alignment and policy frameworks (Akram *et al.*, 2024). Empirical validation for the application of these concepts in practice is provided by case studies spanning manufacturing, electronics and automotive sectors. That said, the degree to which these strategies will be adopted is reliant on context-specific factors such as organisational readiness, technological infrastructure and regulatory landscapes.

Theoretically, this research contributes to the circular supply chain literature in several aspects. First, the proposed model overcomes fragmented and silo-based approaches by integrating reverse logistics, product lifecycle management and zero-waste strategies into a system-level framework. Second, it contributes to closed-loop supply chain research by conceptualising circularity as a dynamic phenomenon evolving through the interaction between operational, strategic and normative dimensions. In this way, the study contributes to better understanding why previous research has found uncertain or contextually dependent consequences when circular practices are adopted in isolation.

From a practical standpoint, the findings provide meaningful implications to managers, industries and policymakers. This integrated model could assist supply chain managers in ensuring that product design decisions are congruent with reverse logistics capabilities and waste reduction objectives. Policy makers should also pay attention to the combination of product design, take back systems and waste reduction targets. In a wider perspective, the model can be employed as a diagnostic instrument for measuring circular maturity and identifying challenges in the current closed-loop supply approach.

Whilst a thorough and informative synthesis of the literature on closed-loop and circular supply chains is provided by this meta-review, certain limitations need to be addressed in order to place the scope and applicability of the findings in context. One notable limitation is that many of the reviewed studies exhibit an industry bias by focusing primarily on the manufacturing and electronics sectors; consequently, only a small number of insights are gleaned from service-based industries, agriculture or healthcare supply chains. This may limit the extent to which the conclusions can be generalised, especially to sectors whose operational dynamics are notably different. A second limitation is that many of the articles selected were conducted in developed economies, particularly the United States, Germany and Japan. This means that the review was unable to capture the distinct challenges, resource constraints and innovative practices present in regions that are developing and less well represented. This geographical bias may constrain the global relevance and inclusivity of the proposed recommendations. There also exists a limitation regarding the temporal scope of the articles selected, as only those published between 2012 and 2025 were considered. Although the aim was to capture the most recent and relevant developments, this may have led to the exclusion of seminal works published before this timeframe. In addition, valuable real-world applications and perspectives that exist outside academic channels may have been omitted as a result of excluding grey literature and insights from non-peer-reviewed practitioners. Finally, a further difficulty is posed by the fact that the circular supply chain field is highly dynamic in nature and is changing rapidly, most notably through the increasing integration of advanced technologies such as AI, blockchain, and Industry 4.0. These groundbreaking innovations are transforming supply chain structures and operations on a continuous basis; hence, the most recent developments may not have been covered adequately. Therefore, although a robust foundation has been provided, to maintain relevance in this rapidly changing field, ongoing updates and future reviews will be critical.

Authors' contributions
All authors contributed equally to the preparation and completion of the manuscript.

Availability of data and materials
Yes, the data and materials used in this study are available upon request.

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