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Circular Supply Chains and Reverse Logistics-Challenges, Solutions, Operational Insights, and Global Impacts on Sustainable Development: A Systematic Review

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Abstract The transition from the unsustainable linear "take-make-dispose" model is crucial for achieving the UN Sustainable Development Goals (SDGs), especially given the environmental footprint of critical sectors like global healthcare. This systematic review, adhering to PRISMA guidelines and PICO framework, appraises challenges, solutions, and impacts of Circular Supply Chains (CSCs) and Reverse Logistics (RL) by synthesizing 26 high-quality articles published since 2010. Findings reveal pervasive, multidimensional barriers across technical (e.g., waste stream complexity, scalability), economic (e.g., high start-up costs, weak incentives), policy (e.g., legislative fragmentation, infrastructure deficits in developing nations), and socio-cultural dimensions (e.g., poor social acceptance). Conversely, the review confirms technological innovation as a central enabler, with quantitative evidence showing significant operational gains: RFID in healthcare reduced lost items daily and decreased infectious waste, while PLA recycling yielded a 59.87% production increase and 22.87% cost reduction. The analysis highlights an urgent need for research expansion beyond the current focus on Europe and Asia to address substantial knowledge gaps in Latin American, African, and Middle Eastern contexts. In conclusion, effective CSC implementation necessitates strategic priorities including robust digital infrastructure investment, policy coherence, enhanced stakeholder engagement, and targeted financial support for SMEs to overcome systemic impediments and fully realize the economic and environmental benefits critical for global sustainability.

Keyword: Circular Supply Chains, Reverse Logistics, Circular Economy, Sustainable Development, Supply Chain Management, Closed-loop Systems.

1 Introduction

A fast-increasing population, a fast-urbanizing population, and a rising standard of living during the last couple of decades have resulted in a dramatic growth of the extraction of natural resources as well as waste generation [1]. The environmental burden extends beyond general waste generation to specific sectors with disproportionate impacts. Recent assessments indicate that the global healthcare sector alone contributes approximately 4% of worldwide greenhouse gas emissions [2]. This emission burden is equivalent to the output of 514 coal-fired power plants operating simultaneously, with a significant portion stemming from global supply chains rather than direct operations [3]. The intersection of SDG 3 (health and well-being) and SDG

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12 (responsible consumption and production) underscores the imperative for healthcare systems to adopt practices that actively mitigate environmental impacts associated with medical supplies, equipment procurement, and disposal processes. while small and medium-sized enterprises (SMEs) (representing over 90% of global businesses) are responsible for an estimated 70% of total environmental pollution, with manufacturing SMEs accounting for roughly 65% of air pollution [4]. These figures underscore the urgency of systemic interventions across diverse economic sectors. Global natural resource extractions since 1970 have more than tripled, increasing pressure on the environment and the planet's ecosystems. Thus, the improvement in the utilization of resources and the management of wastes is considered as one of the important actions to achieve the United Nations Sustainable Development Goals (SDGs) based on the five main pillars: people, planet, prosperity, peace, and partnership [1].

The urgency of resource optimization is further underscored by the fact that renewable energy technologies themselves (while critical for decarbonization) present their own end-of-life challenges. Solar photovoltaic panels and wind turbines, for instance, require systematic recovery mechanisms to prevent the emergence of new waste streams as these technologies reach maturity [5]. This paradox highlights the necessity of embedding circularity principles within all industrial transitions, including those aimed at sustainability. However, the adoption of these enabling technologies remains constrained by the absence of standardized protocols and inadequate digital infrastructure deployment, particularly in resource-limited settings [5]. The development of robust performance measurement frameworks) encompassing environmental, social, economic, and logistical dimensions (has been identified as essential for evaluating transition effectiveness and informing strategic decision-making within circular economy initiatives [3].

Conventional linear models of economic systems motivated by "produce-consume-dispose" philosophy have come under widespread criticism because a significant share of the materials is lost in the form of unrecycled wastes as soon as the consumption phase of the product life cycle is completed. This trend has left the world with environmental problems such as an increase in emissions, biodiversity loss, and loss of agro- and industrial materials [6]. The limitations of linear economic models have been further amplified by recent global disruptions. The COVID-19 pandemic, for instance, starkly revealed the interdependence between environmental sustainability and public health resilience, particularly in resource-intensive sectors such as healthcare [2]. This crisis underscored the critical need for adaptive systems capable of managing resource flows under unprecedented demand fluctuations while minimizing ecological harm. As more proactive responses to such challenges, circular economy-built systems and reverse logistics strategy have been receiving increasing attention as new solutions. Their main function is to conserve the value of products and resources, cut down on waste formation, and return the materials to the product production cycle by recycling, remanufacturing, extraction, and putting them back to use [1, 6, 7]. For instance, the implementation of circular supply chain adoption in the healthcare and food industries has led to a significant reduction in waste and adverse environmental impacts as well as cost efficiencies [6, 7].

The transition toward circular economy models aligns with global sustainability frameworks, including the United Nations' Sustainable Development Goals, the Paris Agreement on climate action, and regional initiatives such as the European Union Green Deal targeting climate neutrality by 2050 [2, 5]. Furthermore, the integration of emerging digital technologies (including artificial intelligence, blockchain, and Internet of Things (IoT)) has been identified as instrumental in advancing resource efficiency and enabling data-driven

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circular supply chain management [5]. Industry 5.0 principles, emphasizing human-technology collaboration, offer additional pathways for personalized resource optimization and waste minimization [2].

However, effective implementation of such options is hindered by several barriers, including weak policy and governance for green packaging, lack of innovation in green packaging, lack of market acceptance of recycled material, lack of necessary infrastructure, and cultural/organizational resistance [6, 7]. Empirical evidence from the healthcare sector reveals significant behavioral and organizational obstacles to circular economy adoption. A comprehensive survey of 379 healthcare professionals across public and private facilities identified substantial management detachment from environmental concerns, coupled with insufficient staff motivation regarding sustainability initiatives [2]. These findings point to critical deficiencies in organizational communication, environmental education frameworks, and awareness-building mechanisms that impede the successful integration of circular principles even when technical solutions exist. Therefore, the scientific value is high in determining barriers, noting and defining operational as well as policy solutions to drive circular flows along value chains, especially in developing countries.

In addition, the importance of reverse logistics and closed-loop supply chains within high-risk sectors such as health was demonstrated during new crises such as the COVID-19 pandemic. A case in point with the mask and equipment decontamination is the importance of reducing the cost, human risk, and contamination to the environment in recycling the masks [7].

Considering the imperative of a circular economy, it is crucial to recognize that the challenge of waste generation persists significantly within industrial sectors. Despite policy efforts, a recent analysis of European Union manufacturing companies from 2010 to 2022 reveals a continuing problem, particularly concerning hazardous waste, which has seen an increase, while non-hazardous waste has only shown a marginal decrease. This underscores the complex interplay of structural and regional factors influencing waste trends and the considerable heterogeneity in waste management policies across different regions. Crucially, while much attention is often directed towards recycling and recovery, the highest priority in the waste management hierarchy (waste prevention at the source) remains under addressed in practice and policymaking. Therefore, understanding these dynamics and addressing the existing gap in proactive waste prevention within the manufacturing sector is essential for developing effective and tailored waste management strategies that align with broader sustainability goals [8].

In general, a systematic review of the problems, solutions, and experiences of circular supply chains and reverse logistics in the world can not only enrich the scientific literature of this field but also might be regarded as strategic recommendations to decision-makers, industrial practitioners, and researchers to accelerate achieving the sustainable development goals [1, 6, 7].

This systematic review was conducted to identify and appraise the challenges, solutions, practices, and impact of reverse logistics and circular supply chains practices in comparison to traditional supply chain management paradigms in relation to sustainable development, around the world.

This study goes beyond existing reviews by providing four original contributions to the literature on circular supply chains and reverse logistics:

(i) It develops an integrated multidimensional framework that simultaneously categorizes technological, economic, policy, and socio-cultural barriers, rather than treating them in isolation.

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(ii) It systematically links operational field evidence (e.g., RFID-enabled healthcare logistics, PLA closed-loop recycling) with sustainability outcomes, offering practice-oriented insights rarely synthesized in prior reviews.
(iii) It highlights geographical and methodological gaps, particularly the over-reliance on secondary studies and the underrepresentation of developing regions, which have not been explicitly mapped in earlier systematic reviews.
(iv) It consolidates quantitative performance indicators across sectors, enabling cross-sectoral comparison of circular supply chain effectiveness.

Despite the growing number of studies on circular economy and reverse logistics, existing research remains fragmented across sectors and methodologies, limiting the transferability of findings to real-world supply chain systems.

Moreover, recent technological advancements (e.g., AI-driven sorting, digital tracking, and bio-based materials) introduced after 2022 have not yet been systematically evaluated within a unified review framework.

2 Material and method

2.1. Skeleton structure of a research question

The research question for this systematic review was developed using the PICO statement. More precisely, in the context of organizations and international supply chains worldwide (Population), the review focuses on the impact of the adoption of circular supply and reverse logistics strategies (Intervention) as opposed to traditional or unidirectional supply chain management strategies (Comparison) on the identification of challenges, solutions, experiences, and impact on sustainable development (Outcome).

2.2. Eligibility criteria

a) Selection Criteria:
Studies were included if the paper was an empirical research (including case studies and field research), systematic review, qualitative or quantitative articles discussing the implementation, barriers, solutions, and experiences regarding the operation of circular supply chains and reverse logistics. The paper also addressed a low-carbon circular supply chain, reverse logistics, the circular economy, and waste management, with particular reference to problems, solutions, and environmentally friendly development outcomes. Literature published since 2010 was reviewed to ensure that the review kept up with current developments and measures. The review included only articles written in English, but high-quality non-English publications were examined as far as possible. The studies included in the review had to be studies that published an abstract and information on the key findings. The sources included peer-reviewed scientific journals and proceedings, international conferences, and review documents from federal, state, and local agencies. No geographical criteria for the source of the study were applied.
b) Exclusion Criteria:
Methods: Exclusion criteria also excluded studies dealing with single linear supply chains, non-peer-reviewed articles, non-scientific commentaries, newsletters, and theoretically and ideologically based articles. Technically complex studies, not involving managerial or sustainability perspectives, were also excluded, as were studies dating back before 2010 or lacking abstracts or complete texts that were steadily available on the internet. Non-English

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articles that could not be accessed and time constraints that made them impossible to include were also excluded.

2.3. Search strategy

A systematic and comprehensive search was carried out based on well-defined and appropriate combinations of keywords related to the research area: ((("circular supply chain" OR "reverse logistics" OR "closed-loop supply chain" OR "circular economy" OR "sustainable supply chain")) OR (("sustainable development" OR "SDGs" OR "environmental impact" OR "social impact"))) AND (("solutions" OR "implementation" OR "case study" OR "barriers" OR "challenges")). Publication years and language were not changed throughout the search process.

2.4. Sources and scope of search

Mainly, PubMed and OpenAlex databases were searched. Using the appropriate keywords, a PubMed search returned a total of 619 papers, of which 618 contained abstracts, and 350 were full-text available online for free. On OpenAlex, the initial search returned 6,834 articles - 4,046 freely available articles, 4,037 within the dates within a year of publication, 4,024 records with an abstract.

2.5. Recruitment & evaluation procedure

The screening and article selection process was conducted according to the PRISMA diagram of flow. The initial identification resulted in 7,453 records from PubMed and OpenAlex. After the cleaning process of duplicate records and the reduction of the records based on the relevance of keywords, about 5,500 records were obtained. An initial screening was done on the abstracts and titles of the articles to exclude irrelevant studies, studies with missing abstracts, or studies outside the required publication range, leaving some 680 articles for evaluation in the second stage. Full-text eligibility screening further excluded non-scientific, non-peer-reviewed, or purely technical articles from the sample, which was then limited to 155 studies. The systematic review concluded with 26 primary articles, having selected studies based on the quality of the studies and their geographical coverage, as well as the type of study.

Figure 1 illustrates the systematic process of literature identification, screening, eligibility assessment, and final selection of studies included in this review.

2.6. Data extraction

Standardized templates of systematic review were employed to record the data of the selected articles regarding the author, year of publication, geographic location, type of study, type of industry, managerial and operational outcomes, major challenges and solutions, and key conclusions. The extracted information was then successively mapped according to the PICO framework and thematic categories of industry and geographical area.

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2.7. Quality appraisal & risk of bias

The quality of the studies was established from the classic PRISMA checklist and the tool for critical appraisal of reviews as well as empirical articles. Studies with a low quality of evidence or scientific strength were left out for fear of potential bias in the review results.

2.8. Data synthesis approach

The analysis of data involved the descriptive and thematic analysis method that emphasized the identification and summarization of the challenges, solutions, practices of the organizations, and implications towards sustainable development. Comparative analysis was performed between industries, geographic locations, and solution implementation types.

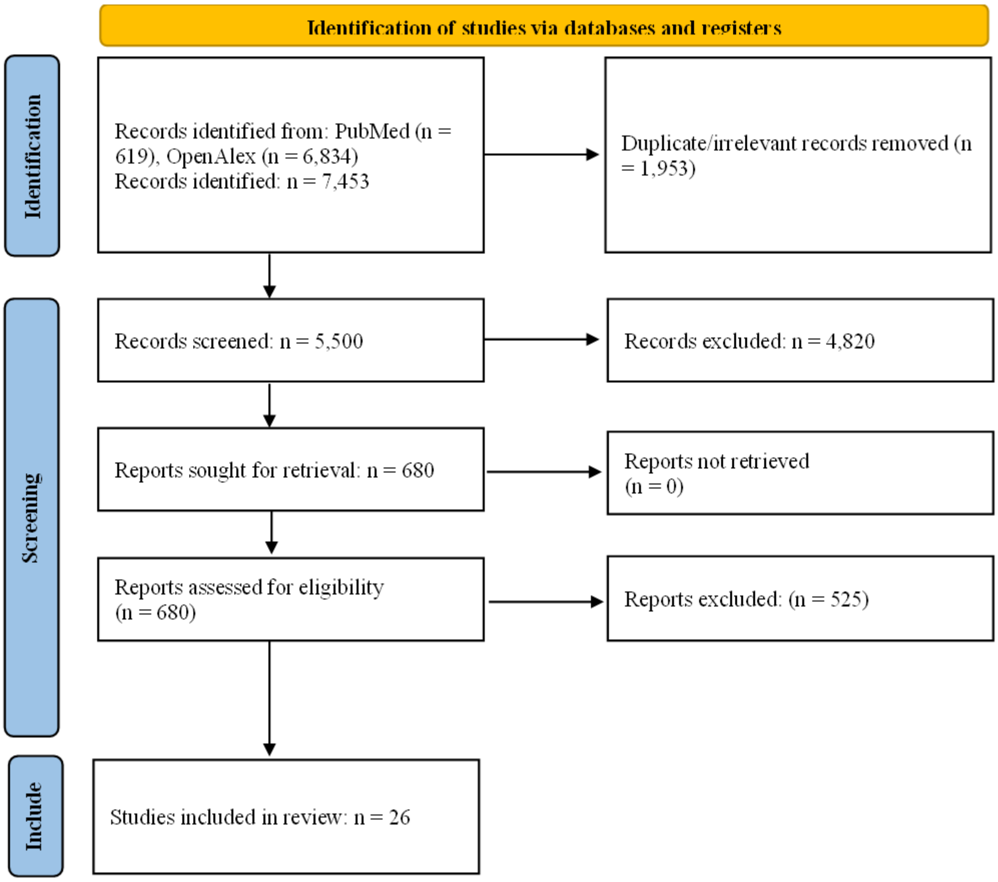

Fig. 1 Flow Chart PRISMA

3. Results

3.1. Study identification and selection trend

With the search and screening process based on PRISMA guidelines, 619 papers were found in PubMed, and 6,834 papers were found in OpenAlex. After removing the duplicates and

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applying inclusion and exclusion criteria (such as relevance of the topic, year of publication, availability of full-text, scientific/peer review, etc.), around 5,500 articles were submitted to preliminary screening. At the first level, according to screening the titles and abstracts, 680 articles that were not focused on the thematic basis or required criteria were excluded. Further evaluation of the full-text and validation by scientific/peer review further reduced the number of articles to 155. Finally, following a final assessment and structured data extraction, 26 articles were finally included as the final studies that should be reviewed.

3.2. Basic features of the research being studied

The included studies range from 2014 to 2025, and they include circular bioeconomy [10, 11], biobased materials and sustainable polymers [12, 13, 14, 15, 16], food supply chains [17, 6], and water and waste management [18, 19, 20, 21]. Geographical coverage varies from Europe and Southeast Asia to Latin America, India, and the transnational regions, to the global level [9, 10, 1, 21]. The methodologies used cover systematic reviews, policy analyses, techno-economic modeling, laboratory and field studies, empirical case studies, and multicriteria analyses [7, 18, 15, 6, 22].

3.3. Comprehensive and interpretive findings

3.3.1. Key challenges

Technical and technological issues, such as the complexity of waste streams treatment, the collection and sorting issues, the performance limitation of some biobased materials, the challenge of scalability in the industrial growth, are cited abundantly in all areas [18, 22, 12, 13, 16, 20]. Economic constraints include high start-up costs, market distortions, lack of economic incentives, and high costs of recycling or production [11, 13, 14]. Policy-related challenges include inter-sectorality and legislative coordination, weak policies of incentives to encourage circular economy adoption, and a lack of standardized data and satisfactory infrastructural provision, especially in developing countries [19, 23, 1, 24, 6, 21]. In addition to this, managerial and cultural challenges like poor social acceptance, insufficient inter-sectoral cooperation, as well as low stakeholder and citizen participation are also frequently cited [25, 26, 27, 21, 6].

3.3.2. Models and solutions for proposal

The researches indicate strategies like policy formulation for inclusion and incentives, use of latest technologies (e.g. RFID in the medicine supply chains or artificial intelligence in the e-waste management), indicator-based management, eco-design ("safe and sustainable by design"), intelligent recycling plants, closed-loop material cycles in industries [28, 7, 22, 29, 12, 15]. The significance of the role of education, the empowerment of the citizens, and proactive involvement of the stakeholders, as well as coordinated policy formulation during the crucial instances during the process of effective implementation, is emphasized [9, 23, 1, 14, 25, 26].

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3.3.3. Field experiences and quantitative

Professional experience of operational success and failure is described. For instance, the production of one hospital in Singapore had the implementation of RFID technology that led to saving 8 lost clothes every day; there was a marked reduction in the cost of stock shortage; the percentage of infectious waste was limited to 15%, and pathological waste to 2% [28]. Zhang et al. [15] reported that PLA recycling led to an increase in the production yield up to 59.87% in addition to a reduction in cost by 22.87%. The other examples, which are based on existing projects in real-world scenarios, include waste-to-energy and the use of biosurfactant, increased recovery rate of heavy metal contents in e-waste, and inter-county management implementation [22, 20, 21, 7, 30, 31]. The main quantitative findings of the selected articles are summarized in Table 1.

Table 1 Summary of findings

Category	Key Findings	References
Thematic Areas	Circular bioeconomy Biobased materials and sustainable polymers Food supply chains Water and waste management	[10, 11] [12, 13, 14, 15, 16] [17, 6] [18, 19, 20, 21]
Geographical Coverage	Europe, Southeast Asia, Latin America, India, transnational regions, and global level	[9, 10, 1, 21]
Methodologies Used	Systematic reviews, policy analyses, techno-economic modeling, laboratory and field studies, empirical case studies, multicriteria analyses	[7, 18, 15, 6, 22]
Technical & Technological Challenges	Complexity of waste streams treatment Collection and sorting issues Performance limitations of biobased materials Scalability challenges in industrial growth	[18, 22, 12, 13, 16, 20]
Economic Challenges	High start-up costs Market distortions Lack of economic incentives High recycling/production costs	[11, 13, 14]
Policy-Related Challenges	Inter-sectoral and legislative coordination issues Weak incentive policies for circular economy adoption Lack of standardized data Inadequate infrastructure (especially in developing countries)	[19, 23, 1, 24, 6, 21]
Managerial & Cultural Challenges	Poor social acceptance Insufficient inter-sectoral cooperation Low stakeholder and citizen participation	[25, 26, 27, 21, 6]
Proposed Solutions & Models	Inclusive policy formulation with incentives Advanced technologies (RFID, AI in e-waste management) Indicator-based management Eco-design (“safe and sustainable by design”) Intelligent recycling plants Closed-loop material cycles	[28, 7, 22, 29, 12, 15]
Implementation Enablers	Education and citizen empowerment Proactive stakeholder involvement Coordinated policy formulation	[9, 23, 1, 14, 25, 26]
Quantitative Outcomes - Singapore Hospital	RFID implementation saved 8 lost clothes daily Reduction in stock shortage costs Infectious waste limited to 15% Pathological waste limited to 2%	[28]
Quantitative Outcomes - PLA Recycling	Production yield increased to 59.87% Cost reduction of 22.87%	[15]
Other Practical Applications	Waste-to-energy projects Biosurfactant utilization Increased heavy metal recovery from e-waste Inter-county management implementation	[22, 20, 21, 7, 30, 31]

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4. Discussion

This systematic review synthesizes current knowledge on circular supply chains and reverse logistics, revealing multifaceted challenges, solutions, and sustainability outcomes across diverse sectors and geographies. The findings illuminate pathways for transitioning from linear to circular economic models while addressing critical implementation barriers.

4.1. Multidimensional barriers to circular economy transition

The identified challenges demonstrate that circular supply chain implementation faces obstacles spanning technical, economic, policy, and socio-cultural dimensions. Technical complexities in waste stream processing and material sorting persist across sectors [18, 22, 12, 13, 16, 20], particularly in emerging economies where infrastructure deficits compound implementation difficulties [19, 23]. Economic barriers, including high capital requirements and market distortions, discourage investment in circular systems [11, 13, 14]. This disproportionately affects SMEs, which, despite representing over 90% of global businesses, lack financial resilience to absorb transition costs [6, 21].

Policy fragmentation emerged as pervasive, with inadequate inter-sectoral coordination and insufficient regulatory frameworks hindering systematic implementation [19, 23, 1, 24, 6, 21]. Socio-cultural barriers, including limited stakeholder engagement and insufficient public awareness, represent underestimated obstacles [25, 26, 27, 21, 6]. Healthcare sector evidence reveals substantial management detachment from environmental concerns and inadequate staff motivation regarding sustainability initiatives [2], underscoring the necessity of comprehensive change management strategies addressing organizational culture.

4.2. Technological innovation as enabler of circular transitions

Technological advancement plays a pivotal role in overcoming operational barriers. RFID implementation in healthcare supply chains achieved quantifiable benefits: 8 lost items saved daily, 15% reduction in infectious waste, and 2% reduction in pathological waste [28]. These findings support the broader argument that Industry 4.0 technologies constitute essential infrastructure for data-driven circular supply chain management [5].

Bio-based materials represent another technological frontier. PLA recycling achieved 59.87% production yield improvement and 22.87% cost reduction, demonstrating the economic viability of closed-loop material systems [15]. AI applications in e-waste management and biosurfactant use for heavy metal recovery illustrate how innovation addresses complex waste stream challenges while creating value from secondary resources [22, 20, 30].

4.3. Policy integration and multi-stakeholder governance

Effective circular economy transition requires coherent policy frameworks aligning incentive structures, regulatory requirements, and stakeholder interests across governance levels [9, 23, 1, 14, 25, 26]. Regional variations in policy effectiveness, particularly between European contexts with established circular economy roadmaps and developing regions with nascent frameworks, highlight the context-dependency of successful approaches [19, 21].

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Inter-municipal cooperation for integrated waste management demonstrates how collaborative governance overcomes resource constraints and achieves economies of scale [21]. The "safe and sustainable by design" approach represents a proactive policy paradigm embedding circularity principles at product development stages [29], aligning with the waste management hierarchy's emphasis on source reduction as the highest priority [8].

4.4. Sector-Specific implementation insights

Healthcare: The sector presents unique challenges due to stringent safety regulations and complex waste categorization [7, 28]. The COVID-19 pandemic revealed both linear supply chain fragility and circular approach potential in managing resource scarcity [7]. The sector's greenhouse gas emissions footprint (approximately 4% globally) underscores sustainable procurement and waste management urgency [2].

Food Supply Chains: Circular economy adoption confronts challenges related to product perishability, food safety regulations, and consumer acceptance of recycled materials [6, 17]. Barriers, including weak green packaging policies and market resistance to secondary resources, necessitate coordinated value chain interventions [6].

Manufacturing: Hazardous waste persistence in EU manufacturing despite policy efforts indicates structural challenges in industrial waste prevention [8]. Construction and demolition waste management exemplifies sectors where material diversity complicates recycling, requiring tailored regional solutions [26].

4.5. Quantitative performance and knowledge gaps

Quantitative findings reveal significant variability in circular economy performance across contexts. However, aggregating outcomes remains challenging due to methodological heterogeneity and inconsistent sustainability indicator reporting [3]. This underscores the need for comprehensive measurement frameworks encompassing environmental, social, economic, and logistical dimensions [3].

Geographical distribution reveals research concentration in European and Asian contexts, with limited evidence from Latin American, African, and Middle Eastern regions [9, 10, 1, 21]. Developing regions face compounded challenges, including inadequate infrastructure, limited technological capacity, and weak institutional frameworks [19, 21, 23]. Localized initiatives, such as annatto seed waste valorization into biochar [20], demonstrate potential for context-appropriate circular solutions.

4.6. Circular bioeconomy as transformation pathway

Transition toward circular bioeconomy represents fundamental restructuring of production and consumption systems [9, 10, 11]. Microbial biotechnology applications for waste-to-chemicals conversion exemplify how biological processes replace fossil fuel-dependent pathways while generating value from organic residues [10, 30]. However, bioeconomy transitions confront sustainability trade-offs, including land-use competition and biodiversity impacts, necessitating comprehensive life cycle assessment [9, 11].

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4.7. Integration with global sustainability frameworks

Alignment with UN Sustainable Development Goals demonstrates the interconnected nature of resource SDG 12 action and sustainable development [1, 5]. The intersection of SDG 3, SDG 12, and SDG 13 underscores systemic linkages between circular economy implementation and broader sustainability objectives [1, 2]. The paradoxical challenge of renewable energy technologies generating end-of-life waste streams highlights the necessity of embedding circularity principles within all industrial transitions [5].

4.8. Future directions and practice implications

Critical knowledge gaps warrant attention. First, emerging technologies introduced after 2022 require systematic evaluation within unified frameworks [5]. Second, the underrepresentation of developing regions necessitates expanded empirical research examining context-specific barriers and locally appropriate solutions [1, 21]. Third, behavioral and organizational dimensions remain insufficiently understood [2, 6]. Fourth, comprehensive performance indicator system development represents an urgent research priority [3].

For practitioners and policymakers, findings suggest strategic priorities: (1) investment in digital infrastructure for supply chain visibility; (2) policy coherence across governance levels; (3) stakeholder engagement platforms; (4) education and capacity-building initiatives; and (5) financial mechanisms supporting circular innovation, particularly for resource-constrained SMEs [1, 5, 6].

4.9. Limitations

This review acknowledges limitations, including English-language restriction, potentially introducing geographical bias, reliance on specific databases, possibly missing grey literature, methodological heterogeneity complicating quantitative synthesis, and temporal lags between implementation and scholarly documentation.

5. Conclusion

This systematic review provides a comprehensive synthesis of current knowledge regarding circular supply chains and reverse logistics, examining challenges, solutions, operational practices, and sustainability impacts across diverse industrial sectors and geographical contexts. Through rigorous analysis of 26 selected studies published between 2014 and 2025, this review establishes an integrated understanding of the transition from linear to circular economic models.

The findings reveal that circular supply chain implementation encounters multidimensional barriers spanning technical, economic, policy, and socio-cultural domains. Technical complexities in waste stream processing and material sorting remain pervasive across sectors, particularly in resource-constrained settings. Economic obstacles, including substantial capital requirements and market distortions, disproportionately affect small and medium-sized enterprises despite their representation of over 90% of global businesses. Policy fragmentation and inadequate inter-sectoral coordination persist as systemic impediments, while socio-

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cultural barriers—including limited stakeholder engagement and insufficient organizational commitment—represent critical yet underestimated challenges to successful implementation.

Technological innovation emerges as a pivotal enabler of circular transitions. Quantifiable evidence from healthcare sector RFID implementation demonstrates tangible operational benefits, including a daily reduction of 8 lost items, 15% decrease in infectious waste, and 2% reduction in pathological waste. Bio-based material systems, exemplified by PLA recycling achieving 59.87% production yield improvement and 22.87% cost reduction, illustrate the economic viability of closed-loop material flows. Digital technologies, including artificial intelligence, blockchain, and Internet of Things applications, constitute essential infrastructure for data-driven circular supply chain management, though deployment remains constrained by the absence of and inadequate digital infrastructure, particularly in developing regions.

Effective circular economy transition requires coherent policy frameworks that align incentive structures, regulatory requirements, and stakeholder interests across governance levels. The review identifies significant regional variation in policy effectiveness, with established European circular economy roadmaps contrasting sharply with nascent frameworks in developing contexts. Proactive policy paradigms, such as "safe and sustainable by design" approaches that embed circularity principles at product development stages, represent strategic opportunities for addressing waste management hierarchy priorities, particularly source reduction.

Sector-specific implementation insights reveal context-dependent challenges and opportunities. Healthcare supply chains confront unique complexities related to stringent safety regulations and waste categorization requirements, while contributing approximately 4% of global greenhouse gas emissions. Food supply chains encounter barriers associated with product perishability, food safety regulations, and consumer acceptance of recycled materials. Manufacturing sectors demonstrate persistent hazardous waste generation despite policy interventions, indicating structural challenges in industrial waste prevention requiring tailored solutions.

Geographical analysis reveals research concentration in European and Asian contexts, with substantial evidence gaps in Latin American, African, and Middle Eastern regions. Developing regions face compounded implementation challenges, including infrastructure deficits, limited technological capacity, and weak institutional frameworks. Context-appropriate circular solutions, such as localized waste valorization initiatives, demonstrate potential for regionally adapted approaches.

The integration of circular supply chains with global sustainability frameworks underscores interconnected relationships between resource efficiency, climate action, and sustainable development objectives. The intersection of SDG 3 (health and well-being), SDG 12 (responsible consumption and production), and SDG 13 (climate action) illustrates systemic linkages requiring coordinated interventions. The paradoxical challenge of renewable energy technologies generating their own end-of-life waste streams emphasizes the necessity of embedding circularity principles within all industrial transitions, including those explicitly aimed at sustainability enhancement.

Critical knowledge gaps warrant scholarly and practical attention. Emerging technologies introduced after 2022 require systematic evaluation within unified analytical frameworks. Underrepresentation of developing regions necessitates expanded empirical research examining context-specific barriers and locally appropriate solutions. Behavioral and organizational dimensions of circular economy adoption remain insufficiently understood, particularly regarding management engagement, staff motivation, and organizational culture transformation. Development of comprehensive performance measurement frameworks

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encompassing environmental, social, economic, and logistical dimensions represents an urgent research priority for evaluating transition effectiveness and informing strategic decision-making.

For practitioners and policymakers, findings suggest strategic priorities including: investment in digital infrastructure, enhancing supply chain visibility and traceability; establishment of policy coherence across governance levels; creation of stakeholder engagement platforms facilitating collaborative problem-solving; implementation of education and capacity-building initiatives addressing knowledge and skill gaps; and development of financial mechanisms supporting circular innovation, particularly for resource-constrained small and medium-sized enterprises.

This review contributes original insights through four primary advances: development of an integrated multidimensional framework simultaneously categorizing technological, economic, policy, and socio-cultural barriers; systematic linkage of operational field evidence with quantifiable sustainability outcomes; explicit mapping of geographical and methodological gaps underrepresented in prior systematic reviews; and consolidation of quantitative performance indicators enabling cross-sectoral effectiveness comparison.

The transition toward circular supply chains and reverse logistics represents a fundamental restructuring of production and consumption systems aligned with global sustainability imperatives. While substantial implementation challenges persist, documented operational successes demonstrate technical feasibility and economic viability across diverse contexts. Realizing circular economy potential requires coordinated action addressing technological infrastructure development, policy framework coherence, stakeholder capacity building, and financial mechanism innovation. Such comprehensive approaches, informed by empirical evidence and adapted to contextual specificities, constitute essential pathways for achieving sustainable development objectives while addressing urgent environmental challenges, including resource depletion, waste generation, and climate change.

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Conflict of interest

The authors give their statement of no scientific or economic conflicts of interest in this study.

AI usage statement

Artificial intelligence tools were used to assist in the translation from Persian to English.

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