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Closed Loop Supply Chain Model with Remanufacturing, Recycling and Refurbishment Processes: A Systematic Review

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Abstract

Supply chain design is a crucial strategic solution that significantly impacts competitiveness, economic development capabilities, and overall economic growth. Ineffective supply chain design can lead to instability within the supply chain. The design of a reverse logistics network (RLN) is both strategic and highly challenging. As environmental sustainability becomes increasingly important, there is a growing emphasis on Closed-Loop Supply Chains (CLSC), which aim to recover value from end-of-life (EOL) products while promoting both economic and environmental sustainability. However, creating an effective CLSC involves significant challenges due to uncertainties such as demand fluctuations, return rates, and return quality. Furthermore, despite extensive research on CLSC models, critical gaps persist, especially regarding the integration of uncertainty management, the optimization of multi-objective trade-offs, and the incorporation of real-time decision-making in CLSC operations. This study conducts a systematic review of 42 published papers from 2013 to 2023, examining key aspects of CLSC models, including complexity, model type, data characteristics, time dynamics, optimization methods, and solution approaches. The findings reveal that existing studies predominantly focus on deterministic models, with limited emphasis on stochastic approaches, machine learning integration, and dynamic adaptation to changing market conditions.

Keywords
Closed loop supply chain, end of life, return rates, return quality.

1. Introduction
In 2050, the global population is projected to exceed 9 billion, with estimates surpassing 10 billion by 2100 (Bhatia et al., 2020). The increasing demand for goods and overall consumption has led to a growing reliance on raw materials and resources

in production processes, which can exert unsustainable pressure on ecosystems. It is crucial to use natural resources, particularly non-renewable ones, judiciously (EMF 2013). To promote sustainability in industrial processes, reverse logistics is essential. This approach aims to reduce the costs associated with managing returned materials and packaging by implementing circular economy principles such as recovery, recycling, reuse, and remanufacturing of materials and products (Johnson et al., 2016). Remanufacturing involves restoring a used or unused product to its original condition and reintegrating it into the distribution system as a "new product" (Govindan K and Hamed, 2017). A closed-loop supply chain (CLSC) is a vital component of the electronics industry, with several sectors adopting CLSC practices to enhance environmental sustainability (Jauhari et al., 2021). Moreover, effective CLSC inventory management contributes to economic sustainability (Viegas et al., 2019). CLSC embodies circular economy principles and considers three aspects of sustainability: businesses embracing these principles can reap economic, environmental, and social benefits (Denyer and Tranfield, 2019). The objective of this literature review is to thoroughly explore the current state of research, emerging trends, and existing gaps in the field of "closed loop supply chain." Through understanding the existing literature and identifying previous research, we aim to provide a comprehensive perspective on the achievements and challenges in this field. By synthesizing these insights, we seek to provide insight into future research directions regarding closed loop supply chains.

1.1. Objectives

A systematic review of the Closed-Loop Supply Chain (CLSC) model that encompasses remanufacturing, recycling, and refurbishment seeks to chart the evolution of research in this area. The review aims to identify trends and developments in CLSC research, analyze publications by year, research methods, and targeted industry sectors, and classify the various models and approaches employed. It will categorize different CLSC models developed within the contexts of remanufacturing, recycling, and refurbishment. Additionally, the review will identify the optimization techniques, algorithms, and methodologies employed in prior studies, as well as examine the economic, environmental, and social factors that influence the efficiency of closed-loop supply chains. It will also address the challenges and barriers encountered in the implementation of remanufacturing, recycling, and refurbishment processes. Finally, the review aims to pinpoint research gaps and offer recommendations for future studies to cultivate more adaptive and sustainable CLSC models.

2. Literature Review

The concept of Closed-Loop Supply Chains (CLSC) has gained increasing attention due to its potential to enhance sustainability by integrating forward and reverse logistics. CLSC aims to minimize waste, reduce carbon emissions, and optimize resource utilization through remanufacturing, recycling, and refurbishing processes. Several studies have explored CLSC models by incorporating sustainability aspects, economic feasibility, and operational efficiency. Several studies have explored different optimization techniques for CLSC design (Jie et al. 2021). analyzed a two-echelon CLSC network where manufacturers produce green products and recycle waste materials. A Stackelberg game model was used to compare centralized and decentralized decision-making, demonstrating that profit-sharing contracts improve coordination and profitability. A Mixed-Integer Linear Programming (MILP) model for CLSC design in the walnut industry, applying metaheuristic algorithms to minimize costs and optimize facility locations (Amiri et al., 2021). Malik and Sarkar (2020) introduced a mathematical model that integrates stochastic demand lead times and variable production costs. Zeballos et al. (2019) proposed a two-stage stochastic MILP model to evaluate the effects of uncertainty in return quality and quantity on CLSC profitability. The findings emphasized the importance of scenario-based planning for optimal supply chain performance. Uncertainty in CLSC arises from fluctuating return rates, demand variations, and unpredictable product quality. Atabaki et al. (2020) developed a robust optimization model incorporating fluctuating costs, collection rates, and recycling expenses. The study highlighted that robust CLSC models are essential for sustainable operations.Durable products such as air conditioners, refrigerators, and electronics present unique challenges in CLSC design.

Reverse logistics plays a crucial role in CLSC by managing the flow of returned products for reprocessing. According to Rogers and Tibben-Lembke (1999), reverse logistics is the process of planning, implementing, and controlling the efficient flow of goods from the consumer back to the point of origin. Govindan et al. (2015) emphasized that CLSC integrates both forward and reverse logistics to ensure a comprehensive approach to sustainable supply chain management. Sustainability is a key driver in CLSC, aligning with the Triple Bottom Line (TBL) framework, which considers environmental, economic, and social aspects. Studies such as those by Elkington (1997) and Maheshwari et al. (2023) highlight that companies are increasingly adopting sustainable practices to reduce costs and comply with environmental regulations. Managing inventory in CLSC presents unique challenges due to uncertainties in product returns, remanufacturing cycles, and demand fluctuations. Several studies have addressed these issues: Economic Order Quantity (EOQ) Models: Schrady (1967) introduced an EOQ model allowing for repair rates, while Nahmias and Rivera (1979) expanded this by considering finite repair rates. Multi-Shipment Policies: Banerjee (1986) proposed an inventory model that optimizes economic lot sizes, demonstrating that joint ordering strategies benefit both manufacturers and retailers. More recent studies, such as Uthayakumar et al. (2012), consider carbon emissions in vendor-buyer inventory models. Learning Effect in Inventory Holding: Wright (1936) introduced the learning effect, which has since been incorporated into inventory models to reflect reduced costs over time due to experience-based efficiency gains (Keachie & Fontana, 1966; Singh et al., 2020). Environmental concerns have led to increased research on carbon emission control in CLSC models. Hua et al. (2011) analyzed carbon footprints in inventory management, while Zhang et al. (2013) conducted a case study on carbon emissions in cement production. Recent studies, such as those by Manna et al. (2023), focus on investments in carbon emission control within CLSC operations.

3. Methods

This study reviews articles addressing the topic of closed-loop supply chains. It outlines previous research and identifies emerging trends for future studies. A systematic literature review was conducted to select, analyze, and evaluate specific knowledge pertinent to a particular research question (Denyer, D., & Tranfield, D. 2009). The review utilized the SCOPUS electronic database, which is recognized as one of the primary repositories for journal reviews. This database has also been extensively used for systematic literature reviews in the domains of operations, logistics, and supply chain management (Govindan et al. 2015; Jayasinghe et al. 2019; Jena et al. 2016). The review adhered to the seven main steps outlined by Maestrini et al. (2017): planning, screening 1, screening 2, screening 3, screening 4, searching, and writing. Each of these steps is detailed in the following subsections (Figure 1).

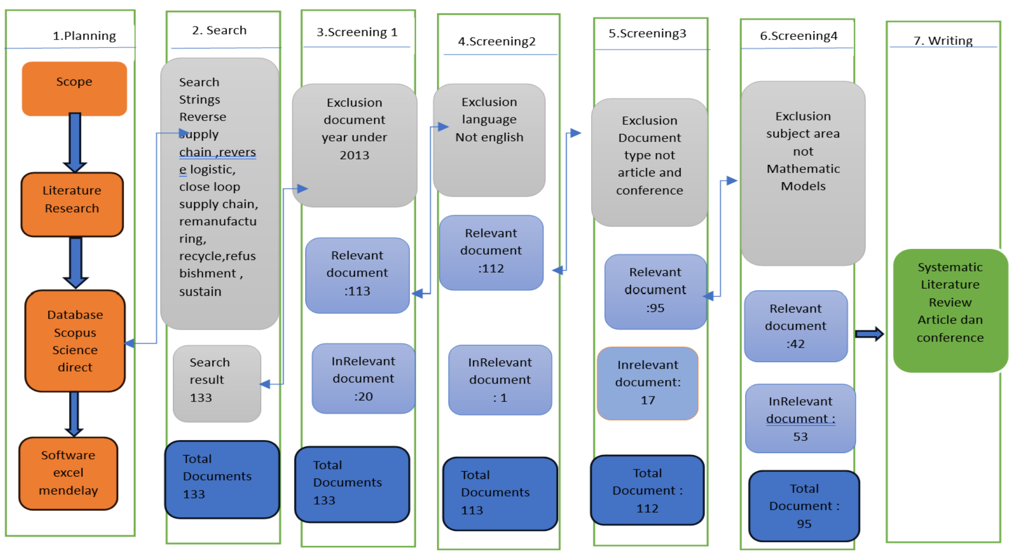

Figure1. Systematic literature review process.

3.1. Planning

The initial stage determined the constructs that this literature review would cover. This study is scoped to focus on Closed-Loop Supply Chain (CLSC) models incorporating remanufacturing, recycling, and refurbishment processes. SCOPUS was selected as the primary database for its extensive coverage. To improve database representation and reduce potential bias, future research may consider incorporating Web of Science, ScienceDirect, IEEE Xplore, and SpringerLink.

3.2 Search

A set of three search strings was formulated after initial exploration and librarian consultation to ensure relevance:

- "Reverse AND supply AND chain OR reverse AND logistic OR closed AND loop AND supply AND chain"
- "Remanufacturing OR remanufactur OR recycling OR recycle OR refurbishing OR refurbishment"
- "Sustainability OR sustainable OR emission OR sustain OR environment"

These strings were applied to title, abstract, and keywords. The initial query returned 133 documents.

3.3 Screening 1

Temporal Filtering

Articles published before 2013 were excluded to focus on recent developments over the past decade. This resulted in 113 documents.

3.4 Screening 2

Language Filtering

Non-English articles were excluded to ensure consistency in comprehension and analysis. The dataset reduced to 112 papers.

3.5 Screening 3

Document Type Filtering Books

Book chapters, and reviews were excluded due to their conceptual nature and lack of empirical model discussion. This narrowed the set to 95 articles.

3.6 Screening 4

Subject Area Filtering

Articles not falling within engineering, environmental sciences, operations research, or applied mathematics were excluded, removing irrelevant social science or unrelated medical papers. The final set included 42 articles.

3.7 Writing

The remaining 42 papers were comprehensively analyzed, leading to insights and the identification of research gaps and trends.

4. Bibliometric analysis and visualization

The growth in the number of articles published annually on reverse supply chains and remanufacturing from 2013 to 2023 is depicted in Figure 2. This Figure 2 illustrates the fluctuations in annual publications, with the peak occurring in 2020, followed by a notable increase in 2023. In contrast, 2021 saw the lowest number of publications. The years 2018 and 2019 experienced a stable number of articles published.

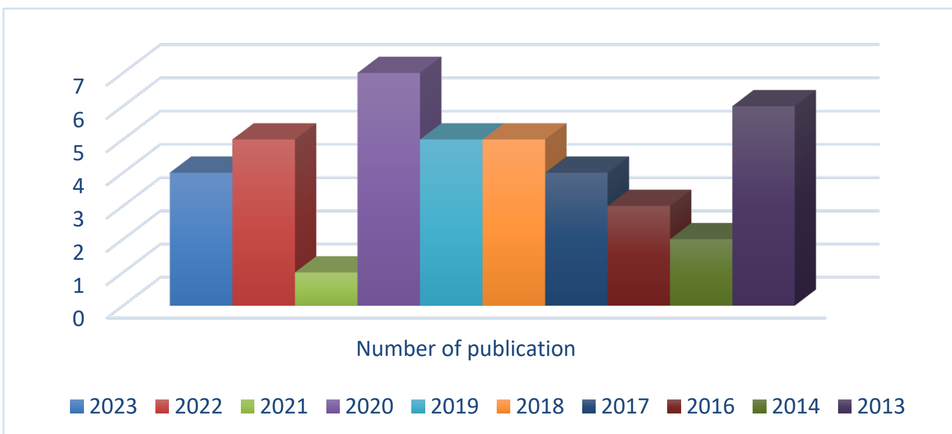

Figure 2. Number of Publications

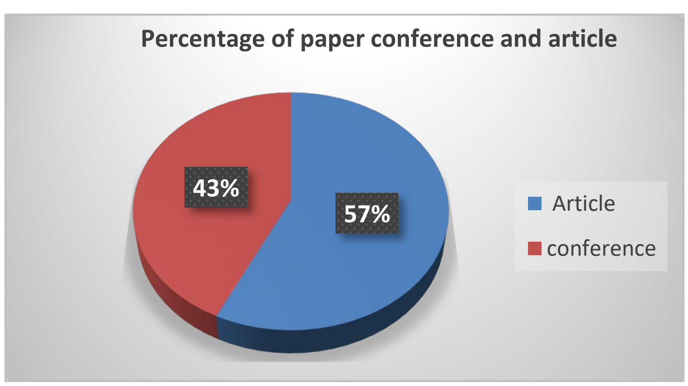

Figure 3. Distribution of Publication Types (Journal vs. Conference Papers)

As illustrated in Figure 3, journal articles account for 57% of total publications, while conference papers comprise 43%. This indicates that journal articles constitute a slightly larger share of the overall publications in comparison to conference papers.

Co-occurrence network analysis serves as an effective method for uncovering relationships between research topics by mapping word pairs into nodes and links, where larger spheres signify stronger connections. Keywords, which appear following the abstract section of an article, include the main terms and other index terms relevant to the document. These keywords encapsulate the primary concepts utilized throughout the article and are directly linked to its perspective (Figure 4).

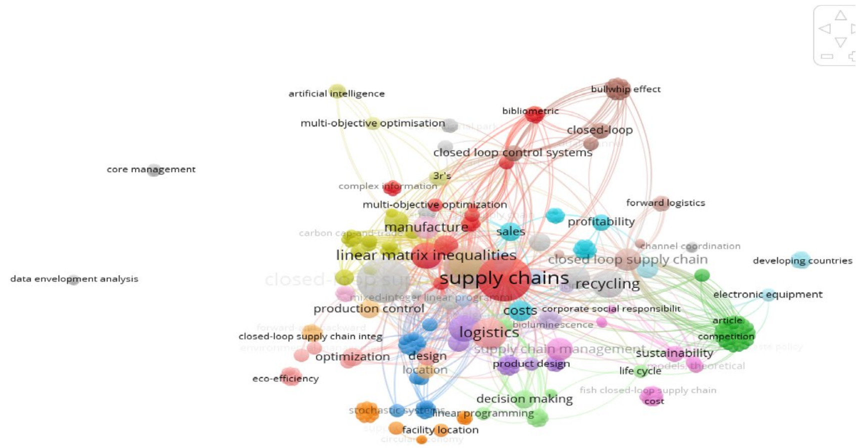

Figure 4. Vos Viewer

The image presented is a network map generated through a bibliometric analysis based on the co-occurrence of keywords from scientific publications. Each node represents a research topic or keyword, while the connecting lines indicate relationships between topics based on their simultaneous appearance within the same documents. Different colors represent clusters or groups of interrelated themes, reflecting the primary directions and focuses of research in the field.

Based on the size and central position of the nodes, several dominant research themes can be identified. The topic of supply chains occupies the largest and most central position, indicating its prominence in the literature. Surrounding this are topics such as logistics and recycling, which frequently co-occur, highlighting the emphasis on efficiency and sustainability in logistics management. Additionally, concepts like closed-loop systems and the circular economy suggest a growing shift toward resource recovery and reuse. Themes such as decision making and optimization illustrate the use of quantitative approaches in managerial decision-making, while the presence of artificial intelligence and data envelopment analysis reflects the adoption of intelligent technologies and analytical methods in research.

However, this network analysis also reveals several significant research gaps. Certain topics, such as data envelopment analysis and core management, appear relatively isolated from the main clusters, suggesting that DEA has yet to be widely integrated into the strategic management of sustainable supply chains. Similarly, the connection between artificial intelligence and multi-objective optimization remains underdeveloped, even though both have great potential to enhance the efficiency and adaptability of complex logistics systems, particularly within the context of circular supply chains. Furthermore, environmental topics such as e-waste and eco-efficiency appear to be underrepresented, indicating limited exploration and the need for further research in electronic waste management.

Based on these findings, several directions for future research are recommended. These include integrating artificial intelligence and optimization methods into circular supply chains to enhance recycling and logistics efficiency; developing strategic management approaches that merge core management with circular economy and closed-loop system practices; and applying data envelopment analysis to simultaneously evaluate the economic and environmental performance of supply chain strategies. Additionally, in-depth studies on electronic waste (e-waste) management through comprehensive reverse logistics strategies are necessary. Finally, the development of decision support systems (DSS) based on AI for multi-criteria decision-making in sustainable logistics represents a highly promising area for further exploration.

Overall, the visualization reveals that supply chains and logistics remain central topics in the current body of literature. However, the integration of advanced technologies (such as AI and DEA) with strategic management, as well as attention to environmental issues, is still relatively limited. Therefore, an interdisciplinary approach that combines quantitative methods, technology, and sustainability is required to develop holistic and adaptive solutions for future supply chain management.

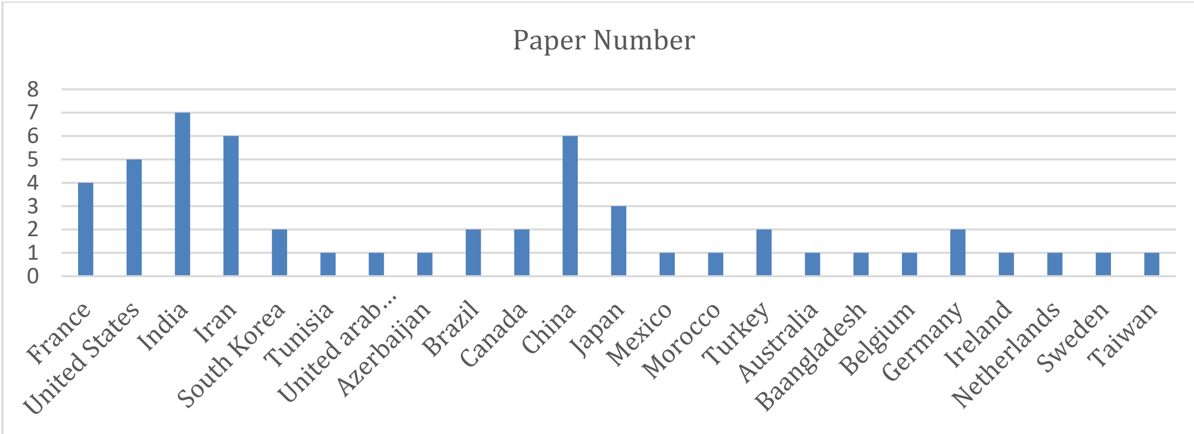

Figure 5. Country and total publication (Top 10)

A total of 10 countries were identified as the sources of the published documents (Figure 5). This section outlines each country's involvement in publishing work on our topic of interest: reverse supply chain and remanufacturing. We present the total number of publications attributed to each country. Figure 4 illustrates the countries and their respective publication totals (Top 10). The bar chart depicts the number of research papers produced in various countries, with the x-axis representing the countries and the y-axis indicating the number of papers. India and China lead with the highest publication counts, each contributing approximately 7 papers, signifying robust research efforts from these nations. The United States and Iran also demonstrate significant contributions, with around 5 to 6 papers each. France, South Korea, and Canada show moderate output, publishing about 2 to 3 papers each. Additionally, several countries including Tunisia, the United Arab Emirates, Azerbaijan, Mexico, Turkey, Australia, Bangladesh, Belgium, Germany, the Netherlands, Sweden, and Taiwan have published only one paper each, reflecting a relatively lower level of research activity in this area (Table 1).

Table 1. A comparison between the proposed model and previous published works.

No	Author	Year	Recovery Mode			Sustainability			Product		Members Involved					
			Rem	Rec	Ref	Env	Ec	Soc	Sl	Ml	S	M	D	R	Cs	Cc
1	Kausar	2023	v	-	-	v	v	-	-	v	-	-	-	v	v	v
2	Talezaidah	2023	v	v	-	-	v	-	v	-	-	v	-	v	v	-
3	Maedah fazihi	2023	-	v	-	v	v	-	-	v	-	v	-	v	v	-
4	Boujelben	2023	v	v	-	-	v	-	-	v	-	v	-	v	-	v
5	Adel A. Alamri	2023	v	-	-	v	v	-	v	-	-	v		v	v	-
6	Hossein e	2022	v	-	v	v	-	v	-	v	-	v	-	v	v	v
7	Mehran ullah	2023	v	v	-	-	v	-	-	v	-	v		v	v	-
8	Maheswari	2022	v	v	-	-	v	-	-	v	-	v	-	v	v	v
9	Gholipour	2022	-	v	-	v	v	-	-	v	-	v	-	v	v	-
10	Prajapati	2022	-	v	v	v	v	-	-	v	v	v	-	v	-	v
11	Checkoubi	2022	v	-	-	-	v	-	v	-	-	v	v	v	v	-
12	Mawandiya	2022	v	-	-	-	v	-	v	-	v	v	-	v	-	-
13	Liao	2022	v	-	-	-	v	-	v	-	-	v	-	v	v	-

No	Author	Year	Recovery Mode			Sustainability			Product		Members Involved					
			Rem	Rec	Ref	Env	Ec	Soc	Sl	Ml	S	M	D	R	Cs	Cc
14	Rajak	2021	v	-	-	-	v	-	-	v	v	v	v	v	v	v
15	Garai	2022	v	-	-	-	v	v	v	-	-	v	-	v	v	-
16	Shekarian	2021	v	v	-	-	v	-	v	-	-	v	v	v	-	v
17	S. Sajedi	2020	v	v	-	-	v	-	-	v	-	v	-	-	v	-
18	Feng	2021	v	-	v	-	v	-	v	-	v	v	v	v	v	v
19	Dominguez	2020	v	-	-	-	v	-	-	v	v	v	v	v	v	v
20	Ullah	2021	v	v	-	-	-	v	v	-	v	v	-	v	-	-
21	Mohammed	2021	v	-	-	v	-	v	v	-	-	v	v	-	v	-
22	Yi shi	2020	v	v	-	v	v	-	v	-	v	-	v	-	-	-
23	Kuvvetli	2020	-	v	-	-	v	-	v	-	-	v	-	v	v	-
24	Mondal	2019	v	-	-	-	v	-	v	-	-	v	-	-	v	-
25	Chuanrui Yang	2020	-	v	-	v	v	-	-	v	v	v	v	-	v	-
26	Mishra	2020	v	v	-	-	-	v	v	-	-	v	-	v	v	-
27	Sarfaraz	2020	v	-	-	-	v	-	v	-	v	-	v	-	-	-
28	Tornese	2019	v	-	-	-	v	-	v	-	-	-	v	-	v	v
29	Atabaki	2019	v	v	-	-	v	-	v	-	-	-	-	v	-	v
30	Pezhman Papen	2018	-	v	-	-	-	v	-	v	-	v	v	-	v	v
31	Hasanov	2018	v	v	-	-	v	-	v	-	-	v	v	-	v	v
32	Wan. P	2019	v	v	-	v	v	-	v	-	-	v	v	-	v	v
33	Johari	2019	-	v	-	v	v	-	-	v	-	v	v	v	-	v
34	Shahparvari	2018	-	v	-	v	-	v	-	v	-	v	-	v	-	v
35	Rezaee	2016	-	-	v	-	-	v	-	v	-	v	v	v	-	v
36	Ghisolfi	2017	-	v	-	-	v	-	v	-	-	v	v	v	-	v
37	Yi-Wen Chen	2015	-	v	-	-	v	-	-	-	v	-	-	-	v	-
38	Dwi Cahyani	2017	v	-	-	-	v	-	v	-	v	-	-	-	v	-
39	Kovacic	2016	-	v	-	v	v	-	v	-	-	-	v	-	v	-
40	Mawandiya	2016	v	-	-	-	-	v	v	-	v	-	-	-	v	-
41	Jung	2014	v	-	-	-	v	-	v	-	v	v	-	-	v	-
42	M.Kannegiesser	2013	v	-	-	-	v	-	-	v	v	-	-	-	v	-

Description

Rem : Remanufactur	env : environment	S : Supplier	D : Distributor
Rec : Recycling	Ec : Economy	M : Manufacturer	Cs : Customer
Ref : Refurbishment	Soc : Social	R : Retailer	CC : Collection Center
SI : Single	MI : Multiple		

Table 1 presents a collection of research studies from 2013 to 2023, focusing on various recovery modes, sustainability aspects, and product involvement.

A. Recovery Mode

A review of 42 studies revealed that remanufacturing is the most frequently discussed recovery mode, featured in nearly 70% of the studies. Recycling was also significant, appearing in about 50% of the studies, often in conjunction with remanufacturing. In contrast, refurbishment was the least examined, with fewer than 20% of the studies addressing this recovery mode. This suggests that remanufacturing is viewed as a more strategic approach within the circular economy framework, as it results in products that are essentially like new. Despite its strong relevance in sectors such as electronics, household appliances, and automotive products, refurbishment remains underexplored. A notable gap identified is the lack of studies investigating hybrid recovery modes, such as the combination of remanufacturing and refurbishment. Additionally, there is limited research focused on determining the optimal recovery mode based on the condition of returned products.

B. Sustainability

In the realm of sustainability, nearly all studies have addressed environmental and economic aspects. However, only about 30% have taken into account the social dimension, which includes factors like labor impacts, community acceptance, and social inclusion. This trend indicates a predominant focus on technical and financial sustainability, with social considerations largely neglected. In reality, achieving genuine sustainability necessitates a balanced approach that integrates environmental, economic, and social factors. Furthermore, there is currently no widely accepted standard or comprehensive framework for evaluating sustainability in product recovery systems, underscoring the need for further development in this field.

C. Product Type

The review indicated that multi-life products are studied more frequently than single-life products. This trend is understandable, as multi-life products align more closely with the principles of a circular economy, facilitating reuse and recovery. In contrast, single-life products have garnered less attention, despite their importance in fast-moving consumer goods (FMCG) sectors such as food, beverages, and hygiene items. This underscores a strong interest in redesigning products to enhance their reusability or recyclability. Nonetheless, single-life products also present opportunities for innovation through eco-design approaches from the outset, including design-for-disassembly or modular design. To date, a comprehensive quantitative comparison between multi-life and single-life products regarding carbon emissions, recycling costs, and social impact has not been conducted, highlighting a potential avenue for future research. Opportunities and directions for future research in the realm of circular economy and product recovery present a range of strategic focuses. One critical area is the examination of refurbishment strategies, which can serve as a cost-effective and swift alternative, particularly in emerging markets. Studying consumer perceptions of refurbished products is essential to grasp the factors that shape their views on quality, stigma, and the attractiveness of these items. Additionally, it is imperative to measure social sustainability using quantitative methodologies to assess social impacts, such as job creation, local community engagement, and poverty alleviation, which may arise from product recovery systems. Moreover, the creation of a Social Sustainability Index (SSI) specifically for product recovery could offer a valuable tool for evaluating broader social impacts.

The integration of digital technologies, including the adoption of the Internet of Things (IoT) and blockchain, is vital for enhancing the efficiency of product take-back processes in a more transparent and measurable manner. Furthermore, the application of artificial intelligence (AI) to predict the remaining lifespan of products and guide decision-making regarding recovery methods—whether remanufacturing, recycling, or refurbishment—can significantly bolster sustainability efforts. In the domain of product design, research into design-for-X principles, such as design for remanufacture, design for disassembly, and modular design, can facilitate the development of products that are easier to recover. Lastly, a cost-benefit analysis of incorporating circular design principles from the early stages of product development warrants further exploration.. On the sectoral front, it is crucial to compare the effectiveness of product recovery across different industries, including electronics, automotive, and medical equipment. This comparison must take into account the various barriers faced by developing countries, such as logistics, regulatory challenges, and technological limitations. Furthermore, the development of collaborative models within the circular supply chain—such as simulations utilizing game theory or agent-based modeling—can facilitate the establishment of appropriate incentive mechanisms that encourage active participation from retailers, distributors, and collectors in the circular economy.

Expanded Discussion: CLSC Models and Circular Economy Frameworks

While this review emphasizes CLSC models in terms of recovery modes and optimization techniques, limited attention has been paid to their integration within established circular economy (CE) frameworks. The Ellen MacArthur Foundation's CE framework, for example, promotes design principles such as maintaining product value, regenerating natural systems, and designing out waste. These principles can complement CLSC design by embedding long-term sustainability strategies beyond technical recovery processes.Furthermore, circular design philosophies like Design for Remanufacture, Design for Disassembly, and modular product architecture can significantly enhance CLSC efficiency. Embedding such principles early in the product lifecycle not only reduces recovery costs but also promotes multi-life product feasibility. Future CLSC models could benefit from adopting these CE-aligned design strategies to enhance sustainability performance.

In addition, interdisciplinary integration—e.g., coupling circular supply chains with digital technologies like blockchain and IoT—can enhance transparency, traceability, and system responsiveness. These enablers can transform traditional reverse logistics into intelligent, real-time responsive networks that support dynamic CLSC execution under uncertainty.

5. Conclusion and Future research

This study offers a systematic review of research on Closed-Loop Supply Chains (CLSC), emphasizing remanufacturing, recycling, and refurbishment. The findings indicate that the majority of CLSC research is centered on supply chain management, logistics, and sustainability. There is a notable shift towards environmentally and economically sustainable supply chain models. India and China stand out as the foremost contributors in terms of research output. Co-occurrence network analysis reveals significant connections between supply chain optimization, decision-making processes, and the integration of artificial intelligence within CLSC studies. Future research should focus on developing more adaptable CLSC models that leverage real-time data, AI technologies, and dynamic decision-making strategies. Furthermore, conducting quantitative sustainability impact assessments is crucial, especially for evaluating economic factors (such as costs and profits) and environmental outcomes (including waste reduction and carbon emission mitigation).

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