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Review

Closing the Gap: A Comprehensive Review of the Literature on Closed-Loop Supply Chains

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Abstract: *Background*: Sustainable closed-loop supply chains have emerged as viable answers to supply chain problems. They can handle environmental damages (e.g., waste) and related social impacts. Closed-loop supply chains (CLSCs) are forward and reverse supply chain networks that have gained popularity in recent years. Recovery options such as reusing, remanufacturing and recycling can be considered in CLSCs. *Methods*: This paper provides a comprehensive evaluation of CLSC journal papers published between 2020 and the present. This study examines and synthesizes 54 papers from major publications in this area, covering a wide range of themes and approaches. This paper aims to respond to the following key questions: (i) What are the current trends and challenges in CLSC research, and how have they evolved since previous literature review papers? (ii) What key variables and objectives have been studied in recent CLSC research, and how have they been operationalized? (iii) What are the gaps and limitations in current CLSC research? To our knowledge, other literature review papers in this field have covered older papers, and recent papers have been ignored in them. Another research contribution of this paper is the taxonomy of it. *Results*: This review article highlights some developing themes and research gaps in the CLSC literature and makes recommendations for further study. *Conclusions*: This paper provides a comprehensive review of papers on closed-loop supply chain networks.

Keywords: closed-loop supply chain (CLSC); sustainable supply chain management (SSCM); reverse logistics (RLs); remanufacturing; green logistics

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1. Introduction

The management of closed-loop supply chains (CLSCs) using optimization techniques emerged in the 1990s as a crucial strategy for modern supply chain management to address the challenges of sustainability and resource efficiency [1]. CLSCs seek to establish a circular economy by incorporating Reverse Logistics (RLs) and recovery options, as opposed to traditional supply chains, which follow a one-way flow from raw material extraction to product consumption and disposal [2]. In a CLSC, products and materials are designed, manufactured, distributed, consumed and ultimately recovered or recycled [3]. The value of the returned products can be more than hundreds of millions of USD for one retailer. It is imperative for the health of our planet, our environment and our species to manage waste using RL and CLSC networks. The general structure of a CLSC is visualized in Figure 1.

CLSCs enable the recovery and/or reuse of valuable resources, reduce waste generation and lessen the environmental impacts of conventional supply chains. CLSCs include activities such as the design of recyclable products, the collection and classification of used products, remanufacturing processes and the development of RL networks [4,5]. CLSC implementation provides numerous benefits. First, it contributes to environmental sustainability by reducing the consumption of fundamental materials, energy and greenhouse gas emissions [6]. Second, it has positive impacts by recuperating and reusing materials and optimizing logistics and inventory management. In addition, CLSCs promote social responsibility by considering the social and ethical implications of supply chain operations, such as equitable labor practices and community engagement [7,8]. This research is motivated by the above points.

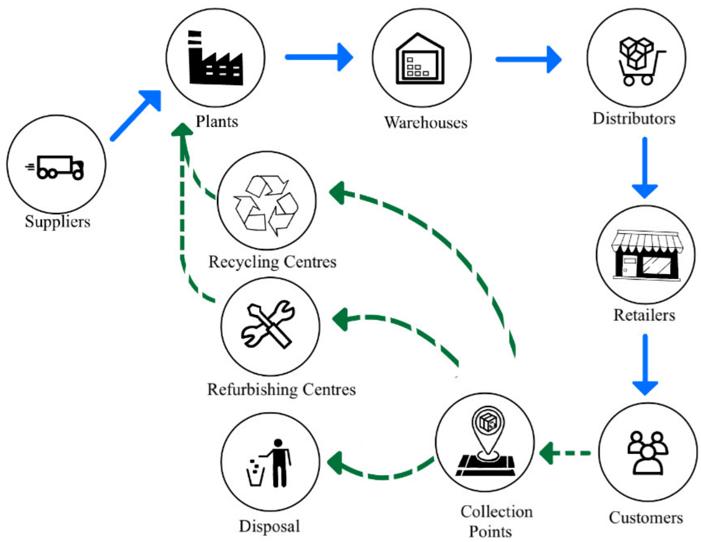

Figure 1. General structure of a CLSC network (forward logistics: ; reverse: logistics).

This literature review seeks to provide an analysis of recent research on CLSC network design and optimization, concentrating on optimization models, including deterministic, uncertain and game-theoretic models, conducted from 2020 to the present. This period was selected because the other literature reviews have covered papers in this field up to 2020. We endeavor to identify the current trends, challenges, and opportunities in CLSC research by analyzing the most recent studies from reputable journal databases. The search is conducted using databases and websites such as Taylor & Francis, Google Scholar, ScienceDirect, Scopus and Web of Science. These databases are popular for conducting literature reviews (e.g., [1]). Prior to revising the results to include what was relevant, targeted keywords such as "design and optimization of closed-loop supply chains" and "green supply chains" were used to locate articles. In addition, we investigated the key variables, objectives and techniques employed in optimizing CLSC networks, as well as the limitations in the current literature. This review contributes to a greater understanding of CLSCs and their potential to transform conventional linear supply chains into environmentally and socially responsible systems. Furthermore, insights are provided for future research and the practical implementation of CLSCs in various industries and contexts by synthesizing the most recent research findings.

The rest of this paper is structured as follows. Section 2 reviews the relevant literature and introduces conceptual classification. Then, the articles are classified accordingly. Section 3 contains a discussion of the observations and suggestions. Section 4 focuses on the findings and future research.

2. Classification

2.1. Conceptual Classification

Four sections compose the conceptual classification. They are literature reviews (LRs), deterministic optimization (DO) models, uncertain optimization (UO) models, and game-theoretic (GT) models. Models of deterministic optimization are mathematical structures used to optimize solutions to well-defined problems with known variables and constraints. Uncertain optimization models, on the other hand, strive to discover optimal solutions while considering the variability in uncertain parameters. Game-theoretic models analyze strategic interactions between multiple decision-makers, considering their preferences, actions, and prospective outcomes to determine optimal strategies. The classification of references is shown in Table 1.

Table 1. Classification of the references based on conceptual classification.

Problem Domain	References
Literature reviews (LRs) (8)	[1,3,5,9–13]
Deterministic optimization (DO) models (14)	[7,14–26]
Uncertain optimization (UO) models (20)	[2,8,27–44]
Game-theoretic (GT) models (12)	[6,45–55]

2.1.1. Literature Reviews

Some literature review papers on CLSCs and RLs are discussed in this section. Ritola et al. [10] and Amin et al. [1] converge on the transformative potential of integrating sophisticated information systems and advanced operations research methodologies to enhance CLSC efficiency. Their findings are indicative of a broader acknowledgment within the literature of the need for robust methodological approaches that can capture the complex dynamics of CLSCs. This is complemented by the work of Simonetto et al. [12], which echoes this sentiment by highlighting the role of Industry 4.0 technologies in transforming risks into opportunities within CLSCs. The insights provided by these authors do not stand in isolation but interlock to form a narrative that champions a progressive shift in the CLSC paradigm—from traditional, linear models to dynamic, circular, and technologically empowered systems.

In parallel, the push towards a circular economy, as scrutinized by Mahmoum-Gonbadi et al. [11], reveals a concerted effort to transcend the prevailing monetary-centric performance measures. Their critical analysis indicates that current CLSC models may not fully encapsulate the principles of circularity, thereby advocating for a realignment of design strategies to embody both economic and environmental imperatives. Supporting this perspective, Gunasekara et al. [13] focus on the practicalities of the acquisition, sorting and disposition of used products within CLSCs. They highlight the necessity of efficient return forecasting and judicious channel selection as essential to upholding the circular economy ethos. Complementing these operational insights, Peng et al. [9] delve deeper into the inherent uncertainties of CLSCs, such as those in the acquisition and market stages, underscoring the complexities they introduce to managing returns and optimizing processes. Complementing these operational insights, Peng et al. [9] extend the discourse on uncertainty within CLSCs, analyzing uncertainties across various stages, including the acquisition and market stages, which align with and further complicate the concerns of forecasting returns, optimizing acquisition efforts and selecting appropriate return channels.

A thematic analysis has revealed that game-theoretic models, examined by De Giovanni and Zaccour [5] and Shekarian [3], serve as a cornerstone for understanding stakeholder interactions within CLSCs. The focus on return functions, product recovery and remanufacturing strategies underscores the significance of strategic decision-making in achieving sustainable and efficient CLSC operations. Furthermore, investigation into contracts and coordination mechanisms points to a need for a holistic perspective that recognizes the multifaceted nature of stakeholder dynamics within CLSCs.

In summary, these reviews highlight key gaps in CLSC research and unify calls for a holistic, technologically advanced, and circular approach. Such integration is essential for future explorations, particularly regarding cost diversity, inventory management and return quality, to further the field.

2.1.2. Deterministic Optimization Models

This section provides a broad collection of research that uses deterministic mathematical models for CLSCs with predetermined parameters to improve different aspects of supply chains, facility layouts and network architectures in the field of deterministic optimization models. Collectively, these studies demonstrate the effectiveness of optimization strategies in promoting sustainability and efficiency in a variety of scenarios.

Allehashemi et al. [19] focused on a dynamic cellphone network situation in Ontario, Canada. This research improved the facility layout within a CLSCN using an MILP model, intending to reduce overall expenses. The model's multi-objective formulation considers factors like CO_2 emissions and quality. Another noteworthy inclusion is the utilization of the fuzzy Quality Function Deployment (QFD) method for managing qualitative elements. The findings show that objective function weights have a considerable influence on facility selection and product flows among them. Valderrama et al. [15] shifted their focus onto a significant issue in the mining industry: reducing Greenhouse gas (GHG) emissions across the supply chain (SC). Their study presents a multi-product, multi-echelon, multi-period environmental mining supply chain network design (SCND) model. This technique, based on an Emissions Trading Scheme (ETS), aims to reduce GHG emissions while optimizing investment, transportation, operating expenses and carbon credits. Valderrama's study gives insights into how certain configurations influence costs and emissions by including ore grade concerns into the SC design, highlighting the usefulness of ETS in decreasing both economic and environmental consequences across the mining SC.

Research by Tirkolaee et al. [7] unveils an MILP model for a sustainable mask CLSC network, where sustainable development is investigated in terms of concurrently reducing total costs, total pollutants and total human risk at the same time. Salehi-Amiri et al. [16] developed an MILP model to construct a cost-effective CLSC network for the walnut industry. The suggested model is validated and improved using exact, metaheuristic and hybrid approaches. The findings demonstrate the importance of changing inventory holding costs, the impact of transportation costs on opening costs and the linear influence of demand on supply chain expenses. Salehi-Amiri et al. [18] designed a closed-loop supply chain (CLSC) for the avocado industry, incorporating avocado seed recycling and compost utilization. That paper shows that the demand's effect on the network strongly affects both cost and employment efficiency objectives through a real-world case study in Puebla, Mexico, using GAMS software and sensitivity analysis.

Santander et al. [14] addressed plastic waste management for open-source 3D printing technology using distributed plastic recycling. An MILP model is employed to assess the economic and environmental sustainability of this dispersed recycling network. The model's effectiveness was shown using a case study from a university. Ahmed et al. [25] introduced a CLSC network for the tire industry, and the model was applied to the Greater Toronto Area in Canada. They addressed both economic and environmental objectives. That paper innovatively incorporates a multi-criteria decision-making method, integrating spherical fuzzy logic to determine supplier weighting factors based on qualitative criteria.

In the realm of green closed-loop supply chain networks (GCLSCNs) during the pandemic, Abbasi et al. [17] demonstrated a model that navigates the trade-offs between cost and CO_2 emissions, focusing on the Iranian automotive industry. Their research highlights the possibility of maintaining supply chain sustainability despite increased operational costs from enhanced hygiene practices, underscoring the resilience and adaptability of these systems during global disruptions.

2.1.3. Uncertain Optimization Models

Uncertainties can arise from a variety of factors, such as shifts in demand, technological advances, disruptions and even lockouts, making supply chains susceptible to unforeseen events. These risks are frequently perceived as both expected and unexpected occurrences, highlighting the dynamic and complex nature of supply chain management [43]. Readers are encouraged to refer to the work of Peng et al. [9] for a comprehensive understanding of the various uncertainty factors affecting CLSCs. They conducted an extensive review of 302 papers, providing insights into the causes of uncertainties at various stages of CLSCs. The sources of uncertainty in the reviewed CLSC papers of this article are shown in Table 2 and Figure 2.

Table 2. Classification of references based on sources of uncertainty.

Source of Uncertainty	References
Demand	[2,8,28–32,34,35,37,38,41–44]
Capacities of resources	[8,28,29]
Recovery rate	[31,37]
Quality	[29,40]
Return	[29–31,35,36,38,40]
Cost	[8,28,29,31,35,40,42,44]

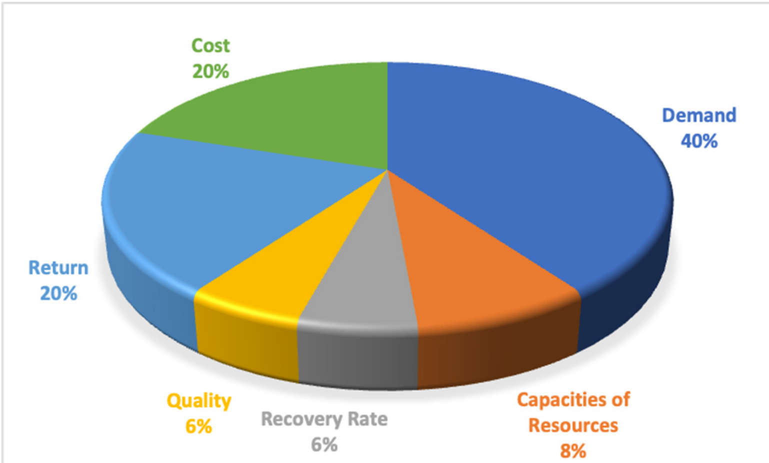

Figure 2. The sources of uncertainty.

Facility location models have recently integrated Sustainable Environmental Strategies (SESs) aimed at minimizing a company's environmental footprint and cost simultaneously [28]. Ruiz-Torres et al. [36] contributed to the literature on CLSCs by presenting a unique model that accounts for numerous suppliers and return sources in a remanufacturing system. In contrast to earlier research, it uses a nonlinear function to simulate return behaviour based on incentives while accounting for uncertainty. In addition, that article investigates a mix of decisions in both forward and reverse flows, emphasizing the importance of supplier portfolio selection and returner incentive methods in improving cost-efficient closed-loop supply chains. Additionally, Wang et al. [33] channeled their efforts into managing hazardous household waste through an RL network that includes collection, treatment, processing and disposal facilities. Multi-objective deterministic and stochastic mathematical models are introduced to optimize facility selection, route planning and waste allocation, aiming to minimize transportation costs and dangers and maximize convenience and participation. With a case study centered around paint waste in the City of Toronto, these models incorporate stochastic parameters such as paint waste generation, recycling rates and diversion rates.

In terms of CLSC models in the mining industry, the study by Akbari-Kasgari et al. [8] is a step up from the study by Valderrama et al. [15] on iron ore, which took a deterministic approach and focused on reducing costs and greenhouse gas emissions without looking at uncertainty or the social side of sustainable development. The model of Akbari-Kasgari et al. [8] includes uncertain parameters and attempts to maximize supply chain profit, reduce water consumption and air pollution, and promote equitable activity allocation in a variety of socioeconomic regions. That study compares two versions of the model (one with and one without backup suppliers) and finds that including backup providers improves supply chain responsiveness and socioeconomic performance while increasing negative environmental externalities. In this vein of advancing CLSCs under uncertain conditions, Xu et al. [44] develop a two-stage stochastic model that tackles the volatility of market demand and carbon pricing within a structured carbon trading scheme. This approach, situated within an eco-friendly CLSC context, offers a flexible and strategic methodology that can be adapted by various industries beyond the aluminum sector, including stainless steel manufacturing and plastic production. The model's robustness in addressing cost and emission management under fluctuating market conditions, as evidenced by the aluminum case simulation results, serves as a guidepost for industries aiming to meet their emission targets amidst uncertainty.

Tosarkani and Amin [28] created a robust, adaptable stochastic model for constructing wastewater treatment networks in hydraulic fracturing operations where costs, demand and resource capacity are uncertain. To address environmental concerns, that paper proposed a bi-objective optimization model that considers both total cost and CO_2 emissions. Its application in Alberta, Canada, was displayed. Similarly, Fathollahi-Fard et al. [27] developed a socially and environmentally responsible water supply network utilizing the Social Engineering Optimizer, a specific optimization technique. The authors claim that this is the first study in the literature to construct a wastewater collection system under uncertain conditions. The study's application tackles real-world water scarcity challenges, namely those in Iran's Urmia Lake.

Research by Khorshidvand et al. [34] revealed a unique hybrid approach, including pricing, greening and advertising options. That study discovered the best levels of advertising and greening decisions to guarantee the chain's profitability. That paper navigated uncertainties and achieved improved outcomes by including a robust scenario-based stochastic programming model, while a Lagrangian relaxation technique enables the effective resolution of large-scale examples. Kchaou-Boujelben [40] created a two-stage stochastic programming model with an unknown return quantity/quality and investigated the implications of return changes on the network's performance and structure. They studied the trade-off between profit maximization and CO_2 emission minimization objectives. They compared their metaheuristic approach to tackling the problem with the ε-constraint technique. Numerical tests show that network setup and performance are sensitive to differences in return quality and quantity, particularly when return processing penalties are significant.

Khalili Nasr et al. [32] presented a two-stage approach for building a SCLSC using the fuzzy best–worst technique and multi-objective mixed-integer linear programming. They did this by integrating economic, environmental, social and circular aspects into supplier selection and order allocation. A case study in the garment manufacturing and distribution industry supports the method, which aims to reduce network costs, environmental impacts and missed sales while enhancing employment opportunities and long-term supplier purchasing. Meanwhile, Shekarian et al. [26] offered a unique mixed-integer linear optimization model for a soybean supply chain network composed of producers, agricultural facilities, distributors and customers. Their approach optimizes profit under uncertain parameters, utilizing a pioneering possibilistic technique. The model was expanded to a bi-objective formulation to account for organic practices, with a case study in Ontario, Canada. It was highlighted that supply chain management approaches may successfully boost consumer satisfaction while lowering costs in food supply chains. For an investigation of the relevant literature on food supply chain management and uncertainty, readers can refer to Shekarian et al. [26] as well as Alinezhad et al. [38], since they offer valuable insights into addressing uncertainties and promoting sustainability in the food supply chain domain. Alinezhad et al. [38] contributed to the field by configuring a sustainable closed-loop supply chain network under uncertain return rate and demand conditions using fuzzy theory, which was validated through a case study in the dairy industry.

2.1.4. Game-Theoretic Models

This section investigates game-theoretic models for CLSCs. Game theoretic models have emerged as important tools for examining complex interactions and decision-making processes across a wide range of fields. In game-theoretic models that explore the interactions and decisions of multiple stakeholders within the framework of a supply chain, strategic decision-making analysis is applied. Researchers have employed game theory to disentangle the complex dynamics of supply chain management, providing possibilities for more sustainable practices and improved supply chain performance.

Zhou et al. [24] developed an equilibrium model for CLSC networks under various remanufacturing approaches while incorporating green factors and allowing decision-makers to choose between in-house and authorized remanufacturing approaches with factors like carbon trading and consumer preferences. Kharaji Manouchehrabadi and Yaghoubi [49] investigated a solar cell supply chain with a closed loop that would recover old solar panels and cause less damage to the environment. Their model is based on dye-sensitized and perovskite solar cells, and the supply chain is made up of a seller, a 3PL provider, and a manufacturer. In the experts' Stackelberg game model of this paper, the 3PL is a follower, while the provider and assembler are chain leaders. The effectiveness of government incentives in promoting solar cell returns was examined. The results indicated that government action significantly improved the situation. Meanwhile, Chai et al. [51] focused on the Electric Vehicle (EV) industry in China, where EV batteries are replaced when their capacity decays to about 80%, generating a significant number of retired batteries. They formulated a Stackleberg game model that consisted of an upstream supplier and a downstream manufacturer. A three-stage model under three different investment schemes was developed. They concluded that process innovation techniques affecting green product remanufacturing may successfully increase remanufacturing performance while raising the manufacturer's recovery rate.

Notably, Fander and Yaghoubi [53] introduced a novel stochastic game model for a closed-loop automotive supply chain, incorporating both static and dynamic fuel considerations. Compared with the authors' previous work [6] that focused on low-consumption cars, this study offers a more comprehensive analysis, emphasizing the dynamic approach's effectiveness in decision-making. The authors significantly extended their previous models on automotive supply chains by introducing a unique stochastic game model, including optimum capacity allocation, cooperative mechanisms for worn-out car collection and the impact of governmental interventions on fuel-efficient technology. Similarly, Lee [47] investigated sustainable strategies in a CLSC, featuring a manufacturer, a retailer and a collector. That paper considers scenarios where the manufacturer and the retailer drive innovation separately or collaboratively, and they examined six different game models using pairings of green innovation strategies and market leadership responsibilities. In-depth game models and analytical solutions revealed the optimal tactics for coordinating green innovation efforts among supply chain participants to achieve a win–win conclusion.

This collection of research also includes studies addressing real-world complexities, such as a study by Hosseini-Motlagh et al. [46], who offer a circular economy-based closed-loop system that incorporates sustainability issues by focusing on a real-world pharmaceutical scenario. The authors introduced an analytical coordination model to manage conflicts resulting from competitive dynamics between a manufacturer and two retailers. A Nash-bargaining game model and a profit-sharing contract were applied to assure the coordination strategy's equitable operation. On a larger scale, Luo et al. [54] addressed the complex relationship between carbon tax policy, manufacturing activities and remanufacturing decisions within closed-loop systems. They developed four game-theoretic models to analyze the impact of the carbon tax on decision-making in both centralized and decentralized contexts. With the evaluation of the impact of three collection strategies (no collection, partial collection and full collection), it was shown that a carbon tax might encourage investment in carbon reduction or remanufactured products to lower carbon emissions.

The literature also includes dual-channel supply chain dynamics, as demonstrated by work by Pal and Sana [55] and Mondal et al. [50]. A study by Pal and Sana [55] digs into the intricacies of a dual-channel supply chain model for eco-friendly goods. The optimal price, rewards for returned products and levels of green innovation are examined using a variety of mathematical models for both centralized and decentralized situations while accounting for competitive channel dynamics. The findings indicate that coordinated decisions regarding green innovation have a positive impact on customers' propensity to return products, and they provide evidence that strategic decision-making and consideration of consumer goodwill may improve market performance. Mondal et al. [50], on the other hand, dig into pricing and greening tactics by dissecting dual-channel supply chain dynamics using several Stackelberg and Nash game models. Situations such as centralized, manufacturer-led decentralized, retailer-led decentralized and Nash games were investigated for pricing and greening strategies. It was found that the centralized method leads to higher retail prices, but the retailer-led decentralized policy yields the highest supply chain profit.

In contrast with earlier papers that have focused on return policies and environmental aspects, Quan et al. [52] presented a novel perspective by addressing the interplay between trade-in services and direct sales in a two-period CLSC game involving a manufacturer and a retailer. That study explores two scenarios: one that is manufacturer-operated (Scenario M) and another featuring retailer-outsourced trade-in services (Scenario R). The authors calculated the relevant Stackelberg equilibrium for each scenario. They studied both scenarios as leader–follower games, looking into decisions regarding rebate rates as well as wholesale and retail prices. Genc and De Giovanni [45] further enrich this framework with the integration of innovation-led lean programs within CLSCs, uncovering that strategic components coupled with process innovation significantly bolster supply chain performance. They posit a novel finding that consumers positively respond to environmentally conscious practices and enhanced operational responsiveness, incentivizing manufacturers and suppliers to adopt strategic lean approaches over purely process innovation-centric approaches. Additionally, the study indicates that centralized systems, free from the constraints of double marginalization, show a clear preference for strategic lean programs, underlining their effectiveness in improving both sustainability and profitability within CLSC frameworks. Zhao et al. [48] offered another angle, focusing on the importance of component reuse. Their CLSC includes a producer, a supplier of new components and a supplier of recycled components. The results demonstrated that product characteristics, particularly for items with low price elasticity, have an impact on this strategy's effectiveness.

2.2. Operations Research Techniques

In this section, a wide range of operations research methodologies applied to diverse CLSC problem domains are discussed. Table 3 includes the details. The reference categorization based on these approaches gives a detailed overview of the numerous techniques utilized to address complex problems. Single techniques and hybrid techniques are provided in this table. In the hybrid techniques, two or more techniques have been combined. In the next section, observations based on this table are discussed. Figure 3 shows mono-objective versus multi-objective functions. Recent papers have focused on multi-objective programming.

The literature is classified in Table 4 depending on the diversity of objective functions (mono-objective and multi-objective). This table lists both single-objective and multi-objective models and specifies the various objective functions used in CLSC optimization. The multi-objective papers generally consider the minimization of costs or maximization of profit in addition to some objective functions related to the environment and/or society.

Table 3. Classification of references based on operations research techniques.

	Techniques	References
Single technique	Mixed-integer linear programming (MILP)	[14,15,18,20,21,26]
	Stochastic programming (SP)	[30,53]
	Meta-heuristics	[22]
	Stackleberg game	[45,47,49,51,52]
	Nash game	[50]
	Nash-bargaining game model	[46]
	Variational Inequality Method (IV)	[24]
Hybrid techniques	SP, MILP	[44]
	Robust probabilistic, two-phase fuzzy	[29]
	MILP, metaheuristics	[16]
	SP, E-constraint, Social Engineering Optimizer (SEO)	[27]
	MILP, E-constraint, Weighted Sum Method (WSM)	[8]
	Multi-objective mixed-integer programming (MOMIP), WSM	[17]
	MILP, Fuzzy Robust Programming (FRP), NSGA-II	[35]
	Robust Flexible Chance-Constrained Model (RFCCM), Distance Method	[28]
	SP, Fuzzy Goal Programming	[56]
	Fuzzy multi-objective mixed-integer linear programming (FMOMILP), Fuzzy Best–Worst Method (BWM)	[32]
	MILP, Robust Optimization (RO), Nonlinear Programming Model (NPL)	[34]
	MILP, 2SP Benders decomposition approach	[33]
	Robust Fuzzy/Possibilistic Stochastic Programing (RFSP), Augmented Epsilon-Constraint Method (AUGMECON)	[31]
	MILP, Fuzzy Goal Programming	[2]
	SP, Non-dominated Sorting Genetic Algorithm (NSGA), Constrained Optimization by Linear Approximation (COBYLA), Pareto Method	[37]
	MILP, Fuzzy QFD, WSM, E-constraint	[19]
	MILP, Pareto-based algorithms	[7]
	Heuristics, Lagrangian relaxation reformulations	[23]
	MINLP, Robust Stochastic Optimization	[39]
	Fuzzy linear programming (FLP), Lp-metric Method, Goal Attainment Method (GAM)	[38]
	MILP, Self-adaptive NSGA-II Algorithm, E-constraint Method	[57]
	MILP, Spherical Fuzzy Logic Method, AUGMECON, VPA	[25]
	Robust fuzzy Probabilistic Method, NSGA, MOPSO algorithm	[42]
	MILP, RO, E-constraint Method, Pareto Front	[43]
	MILP, AUGMECON	[41]
	SP, AUGMECON, Non-dominated Sorting Generic Algorithm (NSGA II), LP Relaxation	[40]
	Stackelberg game, vertical Nash games	[55]

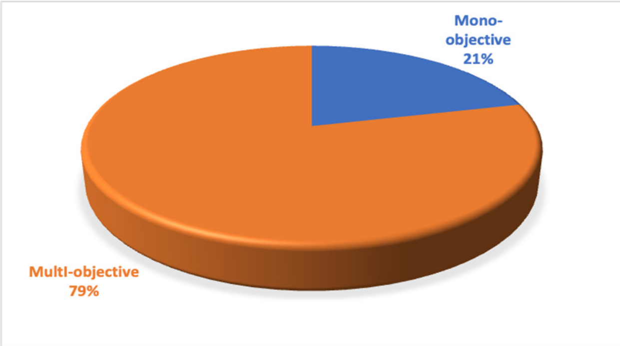

Figure 3. Mono-objective versus multi-objective functions.

Table 4. Types of objective functions.

	Objective Functions	**References**
Mono-objective	Max profit	[26,49]
	Max net profit	[21,30]
	Max sum of economic and environmental benefits	[14]
	Min total system costs	[36]
	Min cost	[16,42]
Multi-objective	Min cost and CO_2 emissions	[15,17,20,29,44,57]
	Min cost, min lost sales	[41]
	Max profit, min CO_2 emissions	[34]
	Min costs, max job employment	[18]
	Min cost, pollution and human risk	[7]
	Max profit and customer satisfaction	[38,45]
	Min total cost, environmental impact	[43]
	Max system profit, min CO_2 emissions	[40]
	Min hybrid of the weighted expected, max and EVaR of the cost function	[39]
	Max profit, min CO_2 emissions, determining optimal price	[53]
	Min cost and CO_2 emissions, max job opportunities	[2,22]
	Max profit and job opportunities, min energy consumption	[23]
	Min costs and risks, max waste collection convenience	[33]
	Min cost and environmental impact, max employment, min lost sales, max procurement value from suppliers	[32]
	Max profit and social benefits, min environmental impact	[8,31]
	Min cost and CO_2 emissions, max positive qualitative factors	[19]
	Min cost, min environmental impacts, max social benefit	[27]
	Max importance of suppliers, min CO_2 emissions, defect rates and withdrawal of surface water by suppliers	[25]

3. Observations and Recommendations

In this section, we conduct a thorough analysis, and we provide recommendations based on the wide range of CLSC papers examined across four different conceptual classifications.

3.1. The Most Popular Domain

In this part, we focus on the papers mentioned in Table 1. According to this table, this literature review reveals a significant shift in focus in the field of CLSC research, with uncertain optimization models emerging as the most popular modelling in recent studies. This conclusion contrasts with the findings of Amin et al. [1], who carried out a comprehensive analysis of publications up to 2020. Notably, their research highlighted the most popular domain as deterministic optimization models, which presume that all parameters are definite. However, CLSC research trends have changed dramatically in this interval. This analysis, which spans the years 2020 to the present, demonstrates that the popularity of uncertain optimization models has risen, indicating a paradigm shift in this research field. This shift can be linked to an understanding of the inherent complexity and uncertainties in CLSCs. Researchers can capture the complicated dynamics of these systems by adding uncertainty to optimization models, allowing for unanticipated disturbances and unpredictable factors. The rise in uncertain optimization models in the modern CLSC environment not only addresses the necessity of dealing with uncertainties but also represents a larger change toward sustainable supply chain management techniques. This change is consistent with the growing realization that efficient supply chain management must address not just economic but also environmental and social factors.

3.2. The Most Popular Sources of Uncertainty

The approach in this part to focus on the papers about uncertain optimization (UO) models mentioned in Table 1. According to a thorough review of the existing literature, the major source of uncertainty in current CLSC research is mostly due to swings in demand. Since the emergence of uncertain optimization models, models have added more sources of uncertainty, increasing their complexity while simultaneously enhancing their accuracy. Regardless of the various other causes of uncertainty, demand was always considered. Several studies have shown this repeated pattern, stressing the relevance of demand uncertainties in defining the design and strategy of CLSC systems. While demand remains critical, the dynamics of CLSC models also show the continual investigation of uncertainty outside demand, such as the return rate and capacities of resources, demonstrating a holistic approach for solving multiple supply chain management difficulties.

3.3. The Most Popular Technique

Operations research techniques were mentioned in Section 2.2. Our approach is to find observations and recommendations based on that section. The most often used method in the field of CLSC modelling is mixed-integer linear programming (MILP), according to the analysis of the data in Table 2. The extensive use of MILP points to its broad applicability in meeting a variety of objectives and restrictions, making it a key technique in closed-loop supply chain optimization.

3.4. The Most Popular Multi-Objective Technique

The ε-constraint approach has been identified as the most popular multi-objective methodology in this review paper. As can be seen, authors have used hybrid techniques, and we observe that the ε-constraint methodology has been mostly used in combination with the MILP technique. This approach is widely used because of its benefits. Notably, it simplifies the computing process by eliminating the need for extra variables, resulting in increased computational performance. Furthermore, it gives researchers control over the number of efficient solutions created by fine-tuning the number of grid points inside the range of each objective function. Unlike other alternatives, it does not demand that distinct goal functions be scaled evenly, allowing each to keep its inherent scale. An important feature is its ability to provide efficient, non-extreme solutions, which contributes to a more nuanced understanding of findings and facilitates complete result analysis. The success of this strategy is based on its efficacy in expediting the multi-objective optimization process while providing essential insights into complex CLSC decision-making scenarios.

3.5. The Most Popular Applications

The applications of the reviewed CLSC models are summarized in Table 5. According to this table, the tire industry is a very popular application.

Table 5. Applications of the models.

	Application	References
Case Study	Automotive industry	[17,21,39]
	Automotive and fuel industries	[6,53]
	Avocado industry	[18]
	Aluminum industry	[44]
	Food industry	[38]
	Garment manufacturing and distribution industry	[32]
	Hydraulic fracturing	[28]
	Mining industry	[15]
	Olive industry	[22]
	Paint waste	[33]
	Pharmaceutical industry	[46]
	Plastic recycling	[14]
	Soybean industry	[26]
	Steel industry	[56]
	Tire industry	[2,25,31]
	Water supply and wastewater collection	[27]
	Wire industry	[41]
Numerical Examples	Battery recycling	[51]
	Cellphone industry	[19]
	Copper industry	[8]
	Electronics	[29]
	Innovation-led lean programs	[45]
	Mask industry	[7]
	Solar cells	[49]
	Supplier selection	[30,36]
	Trade-in services	[52]
	Walnut industry	[16]

3.6. The List of Journals

A summary of the academic journals from which the papers were sourced, along with their respective classifications within the four domains, is given in Table 6. The "Journal of Cleaner Production" was found to have published more papers in this field than any other journal. This table offers an overview of the scholarly environment and offers helpful insights into the distribution of CLSC research across major academic journals.

Table 6. The list of journals.

	Number of Articles				
Journal	**LR**	**DO**	**UO**	**GT**	**Total**
Annals of Operations Research	1	1	1	1	4
Applied Intelligence		1			1
Applied Mathematical Modelling		2		1	3
Clean Technologies and Environmental Policy			1		1
Computers & Industrial Engineering			4	1	5
Energy Sources				1	1
Environment, Development and Sustainability		1	2		3

Table 6. *Cont.*

Journal	Number of Articles LR	DO	UO	GT	Total
Environmental Modelling & Assessment		1			1
Environmental Science and Pollution Research			1		1
Expert Systems with Applications		2			2
Flexible Services and Manufacturing Journal				1	1
International Journal of Environmental Research and Public Health		1		1	2
International Journal of Production Economics	2		2	2	6
International Journal of Sustainable Engineering			1		1
Journal of Cleaner Production	3	2	3	1	9
Journal of Data, Information and Management	1				1
Journal of Environmental Management		1			1
Journal of Industrial and Production Engineering			1		1
Logistics	1		2		3
Operations Management Research				1	1
Opsearch			1		1
Renewable and Sustainable Energy Reviews		1			1
Resources, Conservation & Recycling		1			1
Sustainability				1	1
Transportation Research Part E: Logistics and Transportation Review			1	1	2
Total	8	14	20	12	54

3.7. *Distribution of the Articles*

Table 7 illustrates the distribution of the articles across four CLSC domains for the years 2020–2023. This table provides a fast overview of the publication trends within each domain during this period, highlighting the evolution of CLSC research priorities.

Table 7. The distribution of the journal articles.

	Number of Articles				
Year	LR	DO	UO	GT	Total
2020	4	2	4	6	16
2021	1	1	5	3	10
2022	2	9	6	3	20
2023	1	2	5	0	8
Total	8	14	20	12	54

4. Conclusions and Future Research

This study has focused on the current trends and challenges in CLSC research and how they have evolved since previous literature review papers. In addition, the key variables and objectives in recent CLSC research have been studied. One of the research contributions of this paper is considering new papers in the field (from 2020 to the present). Another research contribution is the taxonomy of this paper, which enables us to analyze the papers in detail.

A thorough review of the literature yielded several notable results as well as areas that require more investigation. Based on the findings of our literature review, we propose the following areas for further research on the subject of CLSC design and optimization.

1. Natural disasters or unanticipated occurrences like the COVID-19 pandemic can disrupt supply chains. Our review found limited CLSC disruption management research. Recently, Akbari-Kasgari et al. [8] proposed a copper industry CLSC model. They incorporated disruption as a source of uncertainty in their model, recognizing

that disruption is widespread in supply networks. They employed scenario-based, two-stage stochastic programming to represent disruption. This method makes early decisions, such as facility establishment, before a disruption and later ones, such as production volumes, depending on interruption scenarios. Interruptions may also modify unforeseen and scenario-based variables like facility capacity usage rates. Future research should investigate strategies while also including knowledge from such studies for developing resilient CLSCs that can adapt to and recover from disruptions efficiently.

2. In the age of big data and sophisticated analytics, combining data science approaches with optimization models is a feasible topic for CLSC research. Future studies should investigate how data-driven approaches like machine learning, deep learning and forecasting methods might help CLSC decision-making. CLSCs will become more effective and responsive because of improved demand forecasting, inventory control and route optimization.
3. Since 2020, there has been a notable increase in the development of models that simultaneously consider cost minimization, environmental impact reduction and social responsibility within CLSCs. This reflects a growing commitment to creating more sustainable and socially conscious supply chain designs by integrating economic, environmental and social dimensions. This multidimensional approach holds promise for fostering ethical and environmentally friendly supply chains. Future research should focus on refining the balance between these dimensions in more hybrid models that contain uncertainties and include additional factors, therefore offering useful tools for supply chain management.
4. In this paper, the applied operations research techniques have been mentioned. There are several operations research techniques (e.g., multi-objective programming methods) that have not been applied in the design and optimization of CLSC networks, and it is valuable to apply them and develop appropriate solution approaches.
5. Other concepts and techniques in supply chain management papers can be combined with CLSC network optimization.

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