Integrating Perishables into Closed-Loop Supply Chains: A Comprehensive Review

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Abstract: In an era where sustainability and efficient resource utilization are paramount, the closed-loop supply chain (CLSC) emerges as a critical approach, particularly in the context of perishable goods. The perishability of products adds a layer of complexity to supply chain management, necessitating innovative strategies for maximizing product life and minimizing waste. This comprehensive review article delves into the integration of perishable products within the framework of CLSC. The study thoroughly examines existing research to identify gaps and outline future research directions. It emphasizes the unique challenges and complexities of managing perishable goods, a crucial but often overlooked component in sustainable supply chain practices. The review highlights the balance between efficiency and sustainability, underscoring the importance of reverse logistics and circular economy principles in enhancing supply chain resilience. By synthesizing various methodologies and findings, the article presents a holistic view of the current state of perishable product management in CLSCs, offering valuable insights for academia and industry practitioners. The study not only contributes to the theoretical understanding of CLSCs, but also proposes practical approaches for their optimization, aligning with broader sustainability goals.

Keywords: closed-loop supply chains; perishable product management; reverse logistics; supply chain management; sustainability; circular economy

1. Introduction

In the evolving landscape of SCM, the concept of a closed-loop supply chain (CLSC) has become increasingly pertinent [1]. This approach is particularly relevant for perishable products, where the balance between efficient supply chain management (SCM) and sustainability is crucial. The CLSC model not only addresses the traditional direct flow of products, but also effectively integrates the process of handling returns, thus enabling a reverse logistic (RL) mechanism [2–4]. The increasing adoption of remanufacturing practices by businesses highlights this approach’s economic and environmental benefits. These practices are further bolstered by governmental regulations aimed at environmental conservation, which mandate the reuse and recycling of materials, creating a sustainable loop in production and consumption [5,6].

However, the design and management of such a supply chain (SC), especially for perishable goods, are complex. One of the major complexities in managing perishable goods is maintaining the quality and extending the shelf life of products such as fresh produce, dairy, and meat. This necessitates stringent time management and temperature control to prevent spoilage, which can lead to substantial financial losses and waste [7]. The cold chain logistics required to maintain a consistent temperature from production to
retail adds further complexity. Any breach in this system can severely degrade product quality, necessitating sophisticated monitoring systems and contingency planning [8].

Additionally, accurate demand forecasting is critical yet difficult due to the perishability of these goods. Overestimating demand leads to waste, while underestimating it results in stockouts and lost sales; thus, advanced statistical models and real-time data analytics are employed to mitigate these risks [9]. Recent studies have also demonstrated the potential of machine learning techniques in improving sales forecasts and managing supply chains more efficiently [10].

Moreover, compliance with stringent regulations on safety, labeling, and transportation adds another layer of complexity, requiring detailed knowledge and adaptive strategies [11]. Effective coordination among multiple stakeholders—suppliers, manufacturers, logistics providers, and retailers—is essential to prevent misalignment, communication breakdowns, and information asymmetry, all of which can increase inefficiencies and spoilage rates [12]. For instance, in the dairy industry, companies like Nestlé utilize advanced temperature sensors and IoT technologies to monitor and control temperatures throughout the supply chain, minimizing spoilage and ensuring safety [13].

Similarly, the rise of e-commerce has prompted companies like Amazon Fresh and Walmart to develop sophisticated logistics networks, including refrigerated storage and rapid delivery systems, to maintain the quality of perishable items, utilizing real-time tracking and predictive analytics for efficient inventory and demand management [14]. Therefore, addressing these multifaceted challenges requires advanced technological solutions and strategic planning to ensure the efficiency and reliability of perishable goods supply chains.

In other words, they must align with varied objectives, including compliance with recycling mandates, meeting consumer demands, achieving profitability, and upholding sustainability goals [6]. Existing models in CLSC primarily focus on cost optimization and profit maximization, with their objectives varying according to product types, services offered, and decision makers’ priorities [15].

The reverse supply chain (RSC) plays a pivotal role in the CLSC, encompassing the flow of products from customers back to suppliers. Companies increasingly design their RSCs as a competitive strategy to address environmental concerns. Enhancing the return rate of products is crucial in order to mitigate environmental challenges such as increased emissions, waste generation, and natural resource depletion [16]. The effectiveness of RSC depends on the cooperative behavior of all SC participants, from suppliers to customers, underlining the importance of a holistic approach that encompasses both product flow and return processes [17]. Pishvae and Torabi showed that supply for manufacturing facilities tends to take the role of implementing such a network for industry productivity and highlighted the benefits of returned products. A CLSC enables us to optimize forward and reverse directions simultaneously [18].

The financial incentives, coupled with heightened customer environmental awareness and stringent regulations, have prompted many manufacturers to offer remanufactured products. Notable examples include Arvin Meritor in North America and Lenovo in the PC industry, which have been engaged in remanufacturing for decades. This trend is also evident in companies like Kodak, Xerox, Siemens, and Caterpillar. The growth in the remanufacturing sector is significant, with global sales surpassing USD 150 billion, highlighting its economic and environmental efficacy [19–21].

Generally, integrating CLSC management into the realm of perishable products presents a multifaceted approach that extends beyond traditional logistics. It necessitates incorporating dynamic factors such as product freshness, environmental conditions, and the complexities of RLs, particularly for sensitive items like fresh produce and biologics. This model not only contributes to sustainable SC practices by emphasizing the importance of recycling and remanufacturing, but also ensures the optimization of resource utilization and minimizes waste. The CLSC, by considering the nuances of perishable product handling and the environmental impact, offers a framework that is both environmentally
responsible and economically viable, proving to be a valuable subject for further research and implementation in various industries handling perishable goods [22–24].

Paper Structure

This paper employs a structured review to explore the integration of perishable products into CLSC. This section outlines the rest of the paper to provide more clarification. The review follows a hierarchical structure to systematically explore the integration of perishable products into CLSC, ensuring a comprehensive analysis from fundamental concepts to specific applications and identifying gaps in current research.

Section 2 presents the methodology employed in the paper in detail. Section 3 establishes a strong theoretical foundation by exploring key concepts in SCM and Green Supply Chains. This includes distinguishing between traditional supply chains, green supply chains, and CLSCs. Fundamental SCM principles are outlined, highlighting their evolution and significance in modern logistics and sustainability practices. The review delves into CLSC, emphasizing its relevance in sustainable practices and reverse logistics. The reprocessing strategies or R-imperatives, such as reselling, reusing, reconditioning, recycling, and remanufacturing, are thoroughly examined. These strategies form the cornerstone of CLSC, enabling the efficient recovery and reuse of products, thus contributing to sustainability.

Section 4 provides an in-depth analysis of CLSC, focusing on optimization and mathematical modeling. The discussion encompasses various aspects of decision making within CLSC, including strategic, tactical, and operational decisions. The literature review covers multi-period models, sustainability aspects, objective functions, applications, and case study sectors.

In Section 5, we focus on perishable products, elaborating on their unique characteristics and challenges in SCM. This includes an analysis of perishability types, such as fixed-lifetime and age-dependent items, and their implications for supply chain operations. The review also examines the impact of perishability on sustainability, emphasizing the need for specialized handling and logistics strategies. Different types of perishability are explored, including fixed-lifetime products like dairy and pharmaceuticals and age-dependent products like agricultural goods. The review discusses the economic and environmental impacts of managing perishable items in supply chains.

Afterward, Section 6 integrates an analysis of CLSC with the specific challenges of managing perishable products. A bibliometric analysis and literature review table provide a comprehensive overview of the current research, identifying trends, methodologies, and gaps in the field. The bibliometric analysis reveals the increasing scholarly attention to CLSC for perishable products, highlighting key authors, publication trends, and the geographic distribution of research. The literature review table categorizes studies based on objectives, models, solution approaches, and industries, providing a detailed reference for researchers.

In Section 7, the review identifies research gaps and proposes future research directions. This includes exploring under-researched areas, such as the integration of social sustainability in CLSC models, and the development of advanced optimization techniques to handle uncertainties in perishable product management. The final section summarizes the key findings and contributions of the review. It emphasizes the importance of integrating perishables into CLSC for the purpose of achieving sustainability goals and highlights the need for continued research to address emerging challenges in this dynamic field.

By following this hierarchical review structure, the article provides a comprehensive and systematic analysis of integrating perishable products into CLSCs, offering valuable insights for academia and industry practitioners.

2. Methodology

This review employs a structured methodology to explore the integration of perishable products into CLSC. The approach encompasses source identification, selection and
evaluation, and data analysis, ensuring a comprehensive and rigorous synthesis of the current research. The following sections outline each step of the methodology in detail.

2.1. Source Identification

The review begins with a comprehensive identification of sources relevant to the integration of perishable products into CLSC. The sources were gathered from multiple academic databases, including Scopus, Web of Science, and Google Scholar, to ensure a wide-ranging collection of articles, conference papers, and reviews. Keywords used for the search included “Closed-Loop Supply Chain”, “Perishable Product Management”, “Reverse Logistics”, “Sustainability”, and “Circular Economy”, “close loop AND network design”.

2.2. Source Selection and Evaluation

From the identified sources, a selection process was implemented to ensure the inclusion of high-quality and pertinent studies. The selection criteria included the publication date; only recent studies published between 2010 and 2023 were considered in order to capture the most recent advancements and trends. Furthermore, relevance criteria are considered; in this regard, articles specifically addressing the CLSC, perishable products and SCM, and integration of perishable products within CLSC frameworks were selected. Lastly, in terms of quality criteria, peer-reviewed journal articles and conference papers were prioritized to ensure the reliability and academic rigor of the sources.

2.3. Data Analysis

The data analysis involved a systematic synthesis of the selected studies to extract relevant information and insights. This analysis was structured hierarchically, beginning with a review of fundamental and theoretical background concepts in SCM and green supply chain, distinguishing them from CLSCs, and discussing reprocessing strategies. Following this, an in-depth analysis of CLSCs was conducted, focusing on decision making, timeframes, sustainability aspects, applications, and case studies specific to CLSC. The analysis then elaborated on perishable products and perishability, detailing the types, challenges, and their impact on supply chain sustainability. Finally, the integration of CLSC for perishable products was explored by conducting a bibliometric analysis and presenting a literature review table to summarize current research and trends.

2.3.1. Bibliometric Analysis

A bibliometric analysis was conducted to quantify the research landscape and identify trends in the integration of perishables into CLSC. For this analysis, the following keywords were searched in the SCOPUS database between 2017 to 2023 based on the following data: “closed AND loop AND supply AND chain”, “supply AND chain AND perishable”. This analysis included tracking the number of publications over the years to observe publication trends, mapping research outputs to identify leading countries and regions in the field, and identifying prolific authors and collaboration patterns within the research community.

2.3.2. Literature Review Table

A comprehensive literature review table was created to summarize key studies in the field. This table included listing the authors and publication year of each study, summarizing the main objectives of the research, describing the models used (such as Mixed-Integer Linear Programming (MILP) or Stochastic Programming), highlighting the solution methods employed (such as heuristic algorithms or exact optimization techniques), and indicating the specific industries addressed in the studies (such as agri-food, pharmaceuticals, or electronics). In general, the details for Table 5 are as follows:

Table 5 reviews recent perishable CLSC studies from 2017 to 2023. To ascertain the current state of perishable CLSC research and establish objectives for the subsequent investigations, a review of the relevant literature is conducted in this work. Table 5
presents the result of the review. This literature review considers only optimization-based approaches to CLSC. By applying this methodology, the review seeks to provide an in-depth review of the state of the field of perishable CSC research, point out knowledge gaps, and define clear recommendations for future research endeavors. These articles are classified and listed according to the authors, years, purposes, model formulation, solution approach, and industries.

The source for this review is SCOPUS articles, which have been indexed since 2017 and up to 2023 using the specific keywords given in Table 1, which are the primary sources used in this article. Articles about perishability in CLSCs were found using these keywords.

**Table 1. Keywords to search for articles.**

<table>
<thead>
<tr>
<th>Search</th>
<th>Keyword</th>
<th>Found Articles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>“Closed-loop supply chain” AND Perishable</td>
<td>17</td>
</tr>
<tr>
<td>2</td>
<td>“Closed-loop supply chain” AND agri-food</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>“Closed-loop supply chain” AND dairy</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>“Closed-loop supply chain” AND fish</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>“Closed-loop supply chain” AND pharmaceutical</td>
<td>8</td>
</tr>
<tr>
<td>6</td>
<td>“Closed-loop supply chain” AND tire</td>
<td>23</td>
</tr>
<tr>
<td>7</td>
<td>“Closed-loop supply chain” AND biotur</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>“Closed-loop supply chain” AND blood</td>
<td>3</td>
</tr>
</tbody>
</table>

Total articles found: 65

During the initial phase of the assessment, 65 articles were identified using the search strategy employed. Following that, a meticulous selection process was carried out, in which only articles relevant to the optimization topic and which aligned with the intended goal of this research were considered. Unfortunately, 16 articles were deemed outside the scope of this study and were therefore excluded from further consideration. Finally, 52 articles met the established criteria, forming the foundation for the subsequent analysis. The use of trustworthy sources and selected keywords provides a complete examination of the current body of research on perishability in CLSCs, laying a solid foundation for this study’s future assessment and analysis. A brief overview of the research methods used in this study is shown in the following Figure 1.

![Figure 1. Overview of research methods employed in the study.](image-url)

Lastly, it should be mentioned that the methodology and approach for this review draw upon the practices and recommendations found in several review papers and recent studies [25–28].
3. Theoretical and Fundamental Background

This section introduces the fundamental concepts used in our comprehensive literature analysis. Initially, it addresses the notions of SCM and green SCs and delves entirely into the CLSC. Exploring these concepts is essential for a deeper comprehension of their boundaries, resemblances, and, notably, the distinctions between these SCs. Such an examination is vital for delineating the scope of our research, which concentrates on CLSCs and the unique challenges they pose to businesses—subsequently, the discussion shifts to perishability, detailing its primary attributes.

3.1. Supply Chain Management

Managing the flow of materials in production and distribution, which is crucial for manufacturing companies, falls under SCM, which encompasses planning, coordination, and control of materials from suppliers to customers.

Traditionally an operational issue, the integration of the SC is now critical for maintaining competitiveness. SCM has evolved, particularly noticeably in Toyota’s Just-in-Time system, aimed at efficient material delivery, inventory reduction, and improved supplier relationships. SCM has also expanded from quality control concepts, like W. Edwards Deming’s 1950s principles of cultivating loyal supplier relationships to enhance quality and reduce costs. SCM, formalized in the early 1980s by R.K. Oliver and M.D., focuses on aligning different firms, from manufacturers to customers, for effective market delivery. This integration enhances customer satisfaction and reduces costs, as all consumer goods undergo numerous business transactions from raw materials to finished products [29–32].

Furthermore, effective integration of supply chain components, including customer integration, supplier integration, and internal integration, is essential for optimizing supply chain performance. These integrations not only enhance supply chain agility, but also contribute significantly to commodity supply chain performance [33].

The Global SC Forum generally identified eight key processes comprising SCM’s core [34]. To better understand this, Table 2 is presented below to show the eight key processes. This table outlines the eight key processes in SCM, detailed in rows. Each process is divided into strategic and operational subroutines. Strategic subroutines include long-term planning activities, while operational subroutines focus on day-to-day tasks. The table’s columns list these activities for each process, providing a comprehensive framework for effective SCM.

3.2. Green Supply Chains

Green SCs engage both suppliers and customers in promoting environmentally friendly practices, enhancing both ecological and economic outcomes [35]. In contrast to traditional SCs, green SCM integrate environmental considerations at several stages, such as product development, raw material selection, manufacturing, distribution, and after-sales services [36]. The development of green SC practices mainly employs two approaches: monitoring and collaboration. The monitoring approach entails the purchasing firm setting benchmarks to evaluate suppliers and their offerings. Conversely, the collaborative approach involves purchasers in actively improving the environmental efficiency of suppliers, focusing on achieving long-term objectives [37]. It is important to recognize that governmental interventions in SCM are increasingly directed towards encouraging sustainable practices. The provision of subsidies and financial incentives has proven effective in spurring investments in sustainability and boosting the performance of green SCs, as evidenced by various studies [38–43]. For instance, Zarreh et al. [38] highlighted the critical role of government intervention in water resource management and examined its impact on green manufacturing practices.
Table 2. Eight Key Processes of SC.

<table>
<thead>
<tr>
<th>Managing Customer Relations</th>
<th>Strategic Subroutines</th>
<th>Evaluate Corporate and Marketing Strategies</th>
<th>Establish Criteria for Classifying Customers</th>
<th>Issue Guidelines for Product/Service Agreement Differentiation Levels</th>
<th>Create a Metrics Structure</th>
<th>Create Guidelines for Distributing Process Improvement Benefits to Customers</th>
<th>Operational Subroutines</th>
<th>Segment customers</th>
<th>Organize the account/segment management team</th>
<th>Conduct internal audits of accounts</th>
<th>Discover opportunities within the accounts</th>
<th>Formulate the product/service agreement</th>
<th>Execute the product/service contract</th>
<th>Evaluate performance and produce profitability analyses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Handling Customer Services</td>
<td>Strategic Subroutines</td>
<td>Formulate a customer service strategy</td>
<td>Create response protocols</td>
<td>Build infrastructure for response procedure execution</td>
<td>Establish a metrics system</td>
<td></td>
<td>Operational Subroutines</td>
<td>Identify significant events</td>
<td>Assess the situation and options</td>
<td>Execute the solution</td>
<td>Track and document performance</td>
<td></td>
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<tr>
<td>Managing Demand</td>
<td>Strategic Subroutines</td>
<td>Select forecasting methods</td>
<td>Organize the flow of information</td>
<td>Establish synchronization protocols</td>
<td>Build a contingency management plan</td>
<td>Establish a metrics framework</td>
<td>Operational Subroutines</td>
<td>Gather data and information</td>
<td>Project future trends</td>
<td>Achieve synchronization</td>
<td>Enhance flexibility and minimize variability</td>
<td>Evaluate performance</td>
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<tr>
<td>Fulfilling Orders</td>
<td>Strategic Subroutines</td>
<td>Assess marketing strategy, SC architecture &amp; customer service objectives</td>
<td>Specify order fulfillment needs</td>
<td>Assess logistics systems</td>
<td>Outline a strategy for order fulfillment</td>
<td>Set up a system of metrics</td>
<td>Operational sub-process</td>
<td>Process and dispatch orders</td>
<td>Enter order details</td>
<td>Execute order processing</td>
<td>Manage documentation processes</td>
<td>Select orders</td>
<td>Fulfill the order</td>
<td>Conduct post-delivery operations and assess performance</td>
</tr>
<tr>
<td>Managing Manufacturing Flow</td>
<td>Strategic Subroutines</td>
<td>Evaluate strategies for manufacturing, sourcing, marketing, and logistics</td>
<td>Assess the need for manufacturing adaptability</td>
<td>Set boundaries between push and pull strategies</td>
<td>Determine manufacturing limitations and needs</td>
<td>Assess manufacturing capabilities</td>
<td>Operational Subroutines</td>
<td>Establish routing and speed through the production process</td>
<td>Plan for manufacturing and material management</td>
<td>Align capacity with demand</td>
<td>Evaluate performance metrics</td>
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</table>
Table 2. Cont.

<table>
<thead>
<tr>
<th>Managing Supplier Relations</th>
<th>Operational Subroutines</th>
<th>Strategic Subroutines</th>
<th>Operational Subroutines</th>
<th>Strategic Subroutines</th>
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<tr>
<td></td>
<td></td>
<td>Examine corporate and manufacturing strategies</td>
<td>Define criteria for classifying suppliers</td>
<td>Issue guidelines for customization levels in the product/service agreement</td>
<td>Construct a metrics framework</td>
<td>Issue guidelines for allocating process improvement benefits to suppliers</td>
<td>Classify suppliers</td>
<td>Set up the supplier/segment management team</td>
<td>Conduct internal evaluations of suppliers or supplier segments</td>
<td>Spot opportunities with suppliers</td>
<td>Develop a product/service agreement and communication strategy</td>
<td>Implement the product/service contract</td>
<td>Assess performance and produce reports on supplier costs and profitability</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Developing and Commercializing Products</td>
<td></td>
<td>Assess sourcing, manufacturing, and marketing strategies</td>
<td>Formulate processes for idea generation and evaluation</td>
<td>Set criteria for membership in cross-functional product development teams</td>
<td>Formulate issues and constraints for product deployment</td>
<td>Set guidelines for new product projects</td>
<td>Define new products and evaluate compatibility</td>
<td>Form a cross-functional team for product development</td>
<td>Formalize the new product development process</td>
<td>Develop and construct prototypes</td>
<td>Decide on manufacturing in-house or purchasing</td>
<td>Identify distribution channels</td>
<td>Launch products</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Managing Returns</td>
<td></td>
<td>Check compliance with environmental and legal standards</td>
<td>Develop guidelines for avoidance, gatekeeping, and handling</td>
<td>Design return networks and processing alternatives</td>
<td>Establish rules for credit management</td>
<td>Identify alternative markets</td>
<td>Accept requests for returns</td>
<td>Plan transportation routes</td>
<td>Process returned items</td>
<td>Choose disposition methods</td>
<td>Provide credit to customers or suppliers</td>
<td>Examine returns and evaluate performance</td>
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</table>
The circular SC represents a progression from both closed-loop and green SCs. It expands involvement to more stakeholders in the chain, extending beyond the originating sector. Additionally, it alters the interactions among these participants. Customers have the option to return the product or its remnants to any participant in the product’s value chain within the same sector or across different sectors [44]. Converting this conceptual framework into practical implementation necessitates strategies and policies to cultivate a more efficient production system [45,46].

Six stages of maturity are recognized, following a systematic progression of typical management tasks: problem identification, goal setting and intervention planning, implementation and operation, and evaluation [47]. Thus, the circular SC acts as a guideline, pinpointing crucial activities, potential challenges, and resources required for a company to proactively develop tools at both the individual and organizational levels to achieve its economic, social, and environmental objectives [48]. In these circumstances, firms must reassess their strategic activities and external collaborations, leading to significant transformations in the value chain for those adopting the circular model [45]. The transformation is summarized in Figure 2.

![Figure 2. Transformation in SCM.](image)

### 3.3. Closed-Loop Supply Chain Management

In recent years, the focus has shifted to RLs in the SCM due to global warming concerns. This involves collecting, repairing, recycling, and disposing of returned products. Considering the environmental impact of SCs, implementing RL can serve as a viable strategy. Utilizing RL can lead to a decrease in carbon emissions, offering an advantage. Often, RL processes contribute to increased long-term profitability for businesses [49]. Companies like Kodak and Xerox have made significant strides in remanufacturing and recycling [50]. Integrating forward and RLs forms a CLSC network [51].

CLSC management aims to optimize value throughout a product’s life cycle, efficiently recovering value from returned products over time [52]. It encompasses forward logistics (material procurement, production, distribution) and RLs for the sustainable recovery of used or unused products and parts [53].

The structure of a CLSC is provided in Figure 3.
3.3. Closed-Loop Supply Chain Management

In recent years, the focus has shifted to RLs in the SCM due to global warming concerns. RLs involve the recovery of used or unused products and parts [53]. Integrating forward and RLs forms a CLSC network [51]. CLSCs actively promote sustainable practices. This is achieved through methods such as environmentally responsible government procurement, corporate social responsibility commitments, and efforts to raise awareness and educate consumers about sustainable consumption.

First, the goals of CLSC management extend beyond the traditional SC focus on cost reduction and efficiency. While conventional SCs primarily aim to maximize economic benefits, CLSCs strive to balance economic, social, and environmental impacts. This means that, in addition to economic efficiency, CLSCs emphasize minimizing resource and energy consumption and reducing pollutant emissions.

Next, the organizational framework within CLSC management incorporates environmental considerations into both internal and external management processes. This integration of sustainability is not typically observed in traditional SCs, which tend to overlook environmental impacts in their operations.

In terms of business strategy, CLSCs adopt a more comprehensive approach by embedding low-carbon and environmental safeguarding principles throughout the entire SC and logistics processes. This strategy permeates every stage of the product’s life cycle, from material sourcing and product design to production and distribution. Such an approach contrasts with the narrower focus of traditional SCs.

The operational methodology also differs significantly. Traditional SCs follow a linear “Cradle-to-Grave” model, where the product’s life cycle begins with suppliers and ends with consumers. In contrast, CLSCs implement a “Cradle-to-Reincarnation” model, promoting a circular and reversible flow of products. This model emphasizes managing products throughout their entire life cycle and transforming waste into new raw materials for other products or applications.

Consumer trends further distinguish CLSCs from traditional SCs. Traditional SCs are driven predominantly by consumer preferences and business operations, whereas CLSCs actively promote sustainable practices. This is achieved through methods such as environmentally responsible government procurement, corporate social responsibility commitments, and efforts to raise awareness and educate consumers about sustainable consumption.

Additionally, the distinction between open-loop and CLSCs is crucial. Open-loop SCs involve the use of materials by different entities rather than the original producers. Conversely, CLSCs involve the return of products to their initial manufacturers for value recovery, including reusing or recycling the entire product or its components [54]. CLSCs extend the concept of RL to encompass activities like remanufacturing, repair, refurbishing, and recycling [55]. Implementing CLSCs requires significant resource investment and the establishment of systems for collecting products at the end of their life cycles [56]. Unlike open-loop SCs, which involve materials from various producers, CLSCs are typically associated with a single manufacturer, underscoring the importance of a coordinated and integrated approach to sustainable supply chain management [57].
By comparing these key aspects, it becomes evident that CLSCs offer a more sustainable and environmentally friendly alternative to traditional SCs, aligning business operations with broader ecological and social goals.

3.3.1. Advantages of an Optimal CLSC Design

The advantages of implementing an optimal and successful model in RL and CLSC are multifaceted, offering significant benefits across various dimensions, which are as follows [52]. One of the primary advantages is the reduction in the cost of returning goods. By streamlining the reverse logistics process, companies can minimize the expenses associated with the collection, transportation, and processing of returned items. This cost efficiency directly translates into improved profitability.

Furthermore, an optimized CLSC design facilitates the increase in the value of unused goods. By efficiently managing the reverse flow of products, companies can recover and resell items that might otherwise be discarded, thereby raising the price of these goods in secondary markets. This capability is particularly relevant in responding to recent developments in non-store shopping and e-commerce, where the ability to handle returns effectively is crucial.

Reducing the return time of products and items returned to the manufacturer for reuse is another critical benefit. A faster return process ensures that products re-enter the market quickly, maintaining their value and reducing the need for extensive reprocessing. This efficiency also supports the provision of various return options for buyers, enhancing customer satisfaction and meeting the growing demand for improved services.

The ability to resell valuable products in secondary markets is enhanced through an effective CLSC design. By ensuring that returned products are inspected, refurbished, and resold, companies can tap into additional revenue streams. This approach aligns with environmental requirements, as it promotes the reuse of products and reduces waste.

Controllability and automation of the return process further contribute to the reliability and durability of goods. Automated systems enable precise tracking of returned items, improving the overall efficiency of the reverse logistics process. Additionally, systematized technical support and after-sales service ensure that products meet customer expectations, responding to technical requests and support needs, including repairs, construction, upgrades, or readjustments.

From a cost perspective, an optimal CLSC design reduces shipping and warehousing expenses by optimizing the flow of goods and minimizing unnecessary storage. This reduction in logistics costs is complemented by a decrease in the time associated with the item extermination cycle, ensuring that products are processed and returned to the market more rapidly.

Improving the database and the ability to track items over their life cycle is another significant advantage. Enhanced tracking capabilities provide valuable insights into product performance and customer preferences, supporting better decision making and strategic planning. Moreover, designing environmentally friendly products in compliance with legal restrictions helps reduce environmental impact and align with sustainability goals.

Finally, an optimal CLSC design reduces risk and enhances brand reputation by demonstrating a commitment to sustainability and ethical practices. Encouraging employee engagement and adherence to ethical requirements further strengthens the organization’s overall performance and public image.

By critically analyzing these advantages, it is evident that an optimal CLSC design not only offers economic benefits, but also supports environmental sustainability and customer satisfaction, making it a valuable strategy for modern supply chain management.

In recent years, there has been a growing focus on the design of CLSCs. Historically, industrial societies have followed a make–use–dispose pattern, where the end-of-life management of products typically results in landfilling or incineration [58]. In this context, it is crucial to introduce new consumption and production approaches to shift towards sustainable development [59].
CLSCs are distinct from traditional SCs, primarily due to their emphasis on reprocessing product flows and operations for recovering products post-use [60]. Organizations implementing CLSC strategies aligned with circular economy (CE) practices can reap environmental, social, and economic rewards. Nevertheless, it is essential to acknowledge that transitioning to CLSCs often involves substantial upfront investments, particularly for establishing facilities for the collection and reprocessing of products at the end of their conventional usage [61]. The design of CLSCs is a critical strategic decision given the long-term implications of such choices. Therefore, it is essential to have effective planning and design tools to carefully evaluate the feasibility of CLSC configurations.

3.3.2. The Reprocessing Strategies or R-Imperatives

In CLSCs, the strategies for reprocessing returned products, referred to as R-imperatives, are pivotal in shaping the efficiency and sustainability of the supply chain network. These strategies encompass a broad spectrum of policies identified in the literature, including well-known processes such as Reselling, Reusing, Reconditioning, Recovering, Repairing, Refurbishing, Remanufacturing, Dismantling, Recycling, and Shredding, as well as lesser-studied options like Donating, Refining, and Retreating.

One significant strategy is Donating, where products unsuitable for markets are given to non-governmental organizations. This not only provides social benefits, but also can potentially earn tax credits for the donating company. This strategy, although less common, highlights the importance of corporate social responsibility in CLSC management. Reselling involves selling used products as-is to secondary markets. This strategy is particularly advantageous for items that retain value despite being previously owned. By reselling, companies can tap into secondary markets, thereby extending the product life cycle and reducing waste. This approach, however, requires a careful assessment of market conditions and product quality to ensure profitability.

Reuse is another critical strategy, where a product or its components are utilized repeatedly without significant repair or refurbishment. This strategy is cost-effective and environmentally friendly, as it minimizes the need for new resources. However, the feasibility of reuse depends on the durability and design of the product, which must withstand multiple usage cycles without significant degradation. Reconditioning involves cleaning and renovating a product to restore it to its original condition without significant upgrades. This strategy is useful for products that have cosmetic defects or minor wear and tear. Reconditioning can improve the marketability of returned products, although it may not be suitable for items requiring substantial technical updates.

Refinery refers to the chemical processing of products for reuse. This strategy is particularly relevant for industries dealing with chemicals and hazardous materials, where safe and efficient recycling processes are crucial. However, refinery processes can be complex and require substantial investment in technology and infrastructure. Repairing is focused on fixing minor defects to restore the original functionality of a product. This strategy is essential for maintaining product value and customer satisfaction. While repairing can be labor-intensive, it is often more cost-effective than replacing the entire product.

Refurbishing involves modifying a product to restore its original technical standards and functionalities. This strategy is common in the electronics and automotive industries, where products can be upgraded to meet current standards. Refurbishing extends the life of products and reduces electronic waste, but it requires technical expertise and access to original components. Remanufacturing is a standardized process of restoring products to as new or enhanced condition. This strategy is highly effective for high-value items such as industrial machinery and electronics. In addition, 3D printing serves as a sustainable reprocessing strategy within a CLSC for perishable products, enabling the restoration and enhancement of product functionalities. This technology produces replacement parts, extends product life cycles, and aligns with remanufacturing principles. By facilitating component modification and customization to meet current standards, 3D printing supports industries requiring technical upgrades. Integrating advanced technologies into manufac-
turing processes is crucial for achieving sustainability goals, providing insights that enhance process optimization and ensure high-quality outcomes in sustainable manufacturing [62].

Remanufacturing ensures that products meet stringent quality standards, making them comparable to new items. However, it requires significant investment in facilities and skilled labor.

Recovery of products can be managed by original manufacturers or third parties, depending on the product’s complexity and the expertise required. This strategy encompasses various levels of reprocessing, from simple repairs to complete overhauls. The success of recovery operations depends on the coordination and collaboration among supply chain partners. Dismantling involves breaking down products into pieces for further processing. This strategy is particularly useful for complex products with valuable components. Dismantling facilitates the efficient recovery of parts and materials, although it can be labor-intensive and requires specialized equipment.

Recycling is the process of reprocessing waste to extract valuable raw materials. This strategy is fundamental to sustainable CLSC management, as it reduces the need for virgin materials and minimizes waste. Effective recycling processes depend on the availability of advanced technologies and infrastructure to handle different types of materials. Shredding mechanically recovers metals and produces residues like plastics, textiles, and glass. This strategy is crucial for processing end-of-life products that cannot be reused or refurbished. Shredding ensures that valuable materials are recovered and can be reintegrated into the production cycle, although it also generates secondary waste that must be managed.

By adopting a critical approach to discussing these strategies, it is evident that each R-imperative offers unique benefits and challenges. The selection and implementation of these strategies must be tailored to the specific context of the supply chain, considering factors such as product type, market conditions, and available resources. A comprehensive and integrated approach to reprocessing can enhance the efficiency, sustainability, and profitability of CLSCs.

Different facilities and technologies are needed for these strategies. Inspection and reselling require quality control and redistribution centers. Recycling and remanufacturing are more technology-based and need specialized facilities and capital investment. Repairing and refurbishing, being skill-based, require higher labor investment [63].

4. Optimization and Dynamics in CLSC

This section delves into the intricacies of decision-making processes, highlighting the balance between short-term operational decisions and long-term strategic planning. It examines the dynamic nature of product life cycles and market channels, emphasizing the adaptability required in CLSC management. The section also explores the critical role of sustainability in shaping the objective functions of CLSCs, underlining the increasing importance of environmental and social considerations. Showcasing practical examples and case studies provides valuable perspectives on the difficulties and prospects involved in executing CLSCs. Furthermore, it discusses the latest modeling approaches and solution techniques, showcasing how technological advancements are shaping the future of SC optimization. Finally, it presents a cohesive solution approach, guiding practitioners and scholars in navigating the complex landscape of CLSCs.

4.1. Decision-Making in CLSC

The literature identifies three categories of decision making within CLSCs: strategic, tactical, and operational. Strategic decisions focus on long-term objectives and involve critical choices such as whether to open or close facilities, expand capacities, opt for appropriate transportation methods, and select technological solutions. These decisions often utilize binary decision variables to guide these choices [63].

Tactical decisions, which are connected to strategic ones, operate on a mid-term basis. They involve tasks such as resource allocation; supplier selection; and planning activities related to procurement, production, and the logistics of distribution or redistribution. This
level of decision making may employ both binary and integer variables to manage transportation flows, adjust inventory levels, set pricing strategies, and oversee fleet composition and allocation. Operational decisions are concerned with day-to-day or week-to-week activities, including specific vehicle routing and the scheduling of production and disassembly tasks. These decisions are essential for the smooth functioning of the supply chain on a granular level [59]. Therefore, most models in CLSC aim to integrate strategic and tactical decisions to prevent sub-optimal outcomes that can arise from a disjointed approach in designing forward and reverse elements in CLSCs. Some studies also strive to incorporate all three levels of decision making, which introduces a significant level of complexity [63–68].

4.2. Timeframes and Product Viewpoints in CLSC

Models in SCM can be categorized based on their time frame. Single-period models are static, focusing on decisions made at the start of a period [69–71]. In contrast, multi-period models are dynamic, optimizing decisions throughout the entire time horizon [72,73]. Many multi-period CLSC models include both strategic and tactical/operational decisions, making them ideal for complex design issues involving multiple decision levels over time. Earlier studies mainly focused on single-product models [74,75]. However, in recent years, multi-product models have become more popular, as evidenced by numerous studies [76–78]. This shift aligns with the growing interest in viewing CLSCs through the lens of industrial symbiosis, where SCs of different products collaborate, exchanging material flows.

CLSC design models have been adapted for different business scenarios, including Business-to-Business (B2B) and Business-to-Consumer (B2C) contexts. In B2C, these models also take into account secondary markets by assessing potential distribution channels [79]. These secondary markets are significant for generating revenue and are particularly advantageous in countries with high demand for such markets. However, marketing products through secondary channels can be more complex than selling new products [80].

4.3. Sustainability Aspects and Objective Functions in CLSC

As the world’s energy demand continues to escalate, the quest for sustainable alternative energy sources is driven by increasing concerns for environmental sustainability [81]. Sustainable CLSCs should address economic, environmental, and social sustainability. A review of mathematical models in this field shows a predominant focus on economic and environmental criteria, with social criteria receiving less attention. Economic objectives are consistently included, except in one study focusing solely on the environmental aspect. Economic objectives started receiving more attention in studies from 2013 onwards, but no study exclusively prioritizes social over economic and environmental factors.

The performance of CLSCs is often measured using indicators for environmental and social sustainability, a critical area for systematic study. Economic dimensions typically involve minimizing total costs, maximizing net profits, and enhancing SC time responsiveness. These indicators are generally independent of the model’s time horizon, with net present value (NPV) used for multi-period assessments. Environmental objectives commonly focus on minimizing emissions (CO₂-equivalent and greenhouse gases) and other impacts like waste generation and energy consumption, including considerations for carbon policies.

Despite the importance of circularity in the transition to a CE, no study in the sample incorporated measures of an SC’s circularity degree into their mathematical models, highlighting a significant research gap. The most important objectives of bi-objective models, combined with cost and profit considerations, are minimizing environmental emissions and maximizing social impacts and network responsiveness [63].

Popular objective functions from the economic, environmental, and social perspectives are presented in Table 3.
Table 3. Popular objective functions.

<table>
<thead>
<tr>
<th>Environmental Indicators</th>
<th>Economic Indicators</th>
<th>Social Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emissions (environmental CO\textsubscript{2})</td>
<td>Cost-based consideration</td>
<td>Fixed and variable job opportunities</td>
</tr>
<tr>
<td>Environmental impacts</td>
<td>Profit-based consideration</td>
<td>Customer satisfaction</td>
</tr>
<tr>
<td>Waste generation</td>
<td>Time</td>
<td>Worker injuries</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>Risk measures</td>
<td>Social responsibility</td>
</tr>
<tr>
<td>Carbon policies</td>
<td>Net present value (NPV)</td>
<td>Missed working days</td>
</tr>
<tr>
<td>Defective rate</td>
<td>Quality-based indicator</td>
<td>Training hours, community service hours</td>
</tr>
<tr>
<td>Greenness score</td>
<td>Flexibility</td>
<td></td>
</tr>
<tr>
<td>Life cycle analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disposal rate</td>
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</tr>
</tbody>
</table>

Objective functions define the goals and performance metrics of CLSC models, serving as critical tools for evaluating and optimizing the supply chain’s efficiency, sustainability, and resilience.

In the context of economic indicators, efficient cost management ensures profitability and competitive advantage. Maximizing net profits by balancing revenue and costs involves strategic pricing, cost reduction, and efficient resource allocation. Reducing lead times and improving responsiveness to market demands help to meet consumer needs and reduce the risk of product obsolescence. Evaluating and mitigating risks associated with supply chain disruptions, demand variability, and other uncertainties fosters robust strategies that ensure continuity and performance. Assessing the long-term financial performance of supply chain investments using net present value (NPV) calculations considers the time value of money, providing a comprehensive view of profitability over time. Maintaining high product quality and reducing defects is crucial for customer satisfaction and waste reduction.

Regarding environmental indicators, minimizing emissions (CO\textsubscript{2}-equivalent and other greenhouse gases) and other impacts such as waste generation and energy consumption is essential. Reducing carbon emissions and optimizing transportation routes, using energy-efficient technologies, and adopting green practices help minimize the environmental impact. Addressing broader environmental concerns such as resource depletion, pollution, and habitat destruction is necessary for reducing the ecological footprint. Effective waste management through recycling, reusing materials, and minimizing excess production reduces waste at all stages of the supply chain. Optimizing energy use by employing renewable energy sources and improving energy efficiency in operations reduces both costs and environmental impact. Adhering to regulatory requirements and industry standards for carbon emissions helps avoid penalties and supports sustainability goals. Reducing defective products minimizes waste and improves efficiency, requiring high-quality production processes and quality control measures. Evaluating the overall environmental performance of the supply chain using a greenness score can include factors like emissions, energy use, and waste management. Assessing the environmental impact of a product throughout its entire life cycle, from raw material extraction to disposal, helps to identify areas for improvement and sustainability. Effective recycling and reuse strategies reduce disposal rates, contributing to environmental sustainability and resource conservation.

In terms of social sustainability, although less frequently addressed, social sustainability is also essential. Creating employment opportunities and ensuring job security for workers contributes to community development and economic stability. Ensuring that products meet customer expectations in terms of quality, availability, and sustainability drives loyalty and a positive brand reputation. Minimizing workplace injuries and ensuring a safe working environment are crucial for employee well-being and productivity. Adopting ethical practices and contributing to societal welfare addresses issues like fair labor practices, community engagement, and ethical sourcing. Reducing absenteeism and improving workforce reliability ensures that healthy and motivated employees maintain supply chain efficiency. Investing in employee training and development, along with
community service initiatives, demonstrates the company’s commitment to social welfare and can enhance employee morale.

By exploring these objective functions in greater depth, we can better understand their roles in creating resilient and sustainable supply chains. This comprehensive approach ensures that the supply chain not only meets immediate operational goals, but also contributes to long-term sustainability and efficiency.

Understanding and integrating stability parameters and objective functions into CLSC models is crucial for creating robust and sustainable supply chains. This detailed exploration highlights the significance of balancing economic, environmental, and social goals, ultimately driving more effective and comprehensive supply chain management practices.

4.4. Applications and Case Study Sectors

Regarding the validation of proposed models in the reviewed articles, a significant number are validated using numerical examples with randomly generated data. The rest employ case studies that are somewhat based on real-world scenarios.

The most common case study industries are stated as follows: Automotive Components [82]; Containers and Packaging [83]; Electronic and Electric Equipment; Instruments and Components [84]; Commercial Services and Supplies [85]; Food Products [86]; Generic Manufacturing [87]; Paper and Forest Products [88]; Metals and Mining [89]; Healthcare Equipment and Supplies [90]; Fast-moving consumer goods [91]; and Oil, Gas and Consumable Fuels [92].

4.5. Modeling Approaches and Solution Techniques in the CLSC

Existing CLSC models can be broadly categorized into deterministic and non-deterministic types. Deterministic models, which account for 43% of the approaches, assume that all parameters and variables are known with certainty. These models are typically simpler and easier to solve, but may not capture the complexities and uncertainties inherent in real-world supply chains. In contrast, non-deterministic models, incorporate uncertainties such as demand fluctuations, return quantities, and other stochastic elements. These models are essential for realistically representing the variability and unpredictability in supply chains, making them more robust and applicable to real-world scenarios [93].

Non-deterministic approaches are further divided into several types, each addressing different aspects of uncertainty and their frequency of use or focus in research as follows [63,94]: Deterministic (17%), Stochastic (16%), Fuzzy (12%), Robust (2%), Robust Stochastic (2%), Fuzzy Robust (2%), Fuzzy Stochastic (1%), Robust Fuzzy Stochastic (1%), Conditional value-at-risk (1%), and Other (4%).

The breakdown of these approaches highlights the diverse methods researchers use to manage uncertainties in CLSCs. Stochastic models, being the most prevalent non-deterministic approach, focus on probabilistic scenarios and random variables. Fuzzy models handle vagueness and imprecision, while robust models provide solutions that remain effective under a range of possible scenarios. Hybrid approaches like robust stochastic and fuzzy stochastic models combine these techniques to address multiple layers of uncertainty simultaneously.

Understanding the distribution and application of these modeling approaches is crucial for identifying the best strategies for different types of CLSCs. This insight helps practitioners and researchers select appropriate models based on the specific uncertainties they face, leading to more resilient and efficient supply chain designs.

Overall, the prevalence of non-deterministic models in SCM highlights the growing emphasis on managing uncertainty. This trend indicates a shift towards more advanced models that accurately capture real-world SC complexities, especially in perishable goods scenarios. These goods introduce further complexity with their limited shelf life and the necessity for adequate returns management.

There are two distinct categories of optimization techniques: exact optimization methods, which ensure the identification of an optimal solution, and heuristic optimization methods.
methods, which do not assure an optimal outcome. Typically, an exact optimization approach is selected when it can address an optimization issue in a manner where the required effort increases polynomially with the size of the problem [95].

Generally, the following Table 4 presents the most common modeling approaches and solution methodologies in the context of our review. In other words, these modeling approaches and solution methodologies are critical for designing and operating SCs that are resilient, efficient, and capable of handling the return flows of goods, recycling, remanufacturing, and redistribution, all while considering the various sources of uncertainty and complexity inherent in such systems.

Table 4. The most common modeling approaches and solution methodologies.

<table>
<thead>
<tr>
<th>No.</th>
<th>Modeling Approaches</th>
<th>No.</th>
<th>Solution Methodologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mixed Integer Linear Programming</td>
<td>1</td>
<td>Exact</td>
</tr>
<tr>
<td>2</td>
<td>Mixed Integer Non-Linear Programming</td>
<td>2</td>
<td>Metaheuristics</td>
</tr>
<tr>
<td>3</td>
<td>Mixed Integer Programming</td>
<td>3</td>
<td>Fuzzy optimization</td>
</tr>
<tr>
<td>4</td>
<td>Stochastic Programming</td>
<td>4</td>
<td>Robust optimization</td>
</tr>
<tr>
<td>5</td>
<td>Fuzzy Mixed Integer Linear Programming</td>
<td>5</td>
<td>Simulation</td>
</tr>
<tr>
<td>6</td>
<td>Linear programming</td>
<td>6</td>
<td>Heuristics</td>
</tr>
<tr>
<td>7</td>
<td>Fuzzy linear programming</td>
<td>7</td>
<td>Possibilistic approaches</td>
</tr>
<tr>
<td>8</td>
<td>Nonlinear programming</td>
<td>8</td>
<td>MCDM 1</td>
</tr>
<tr>
<td>9</td>
<td>Robust mixed integer linear programming</td>
<td>9</td>
<td>Stochastic optimization</td>
</tr>
<tr>
<td>10</td>
<td>Stochastic Robust optimization</td>
<td>10</td>
<td>Stochastic Robust optimization</td>
</tr>
</tbody>
</table>

Note: 1 Multiple-criteria decision making.

4.6. Integration of Applications, Case Locations, Modeling Approaches, and Solution Methods

The application of CLSC models varies significantly across different industries and geographic locations, reflecting the diverse challenges and opportunities present in each context. Understanding the interplay between these factors is crucial for developing effective and tailored solutions. This section explores the connection between modeling approaches, solution methods, and their applications in various industries and locations.

CLSC models have been applied across a wide range of industries, each with unique characteristics and requirements. On the other hand, case studies often reflect the specific geographic and industrial contexts. For example, in the automotive industry, case studies are frequently located in regions with significant manufacturing activities, such as North America, Europe, and Asia. The food products industry often features case studies from regions with large agricultural sectors, such as the United States, China, and India. Each location brings its unique set of logistical, regulatory, and environmental challenges that influence the design and implementation of CLSC models.

The selection of modeling approaches and solution methods is critical in addressing the specific challenges of each industry and location. In terms of deterministic models, these models assume certainty in all parameters and are often used in industries with stable and predictable environments. For example, deterministic models are frequently applied in the manufacturing of durable goods, where demand and supply conditions are relatively stable. MILP is widely used across various industries due to its flexibility in handling complex optimization problems. It is particularly prevalent in the automotive and electronics industries, where there are numerous constraints and variables to consider.

MINLP is used in industries where non-linear relationships between variables are significant, such as in energy equipment and services. This approach helps in optimizing processes that involve non-linear dynamics. Furthermore, a stochastic programming approach is essential for industries with high levels of uncertainty, such as the food products and pharmaceuticals industries. Stochastic models help in managing the risks associated with demand variability and supply disruptions.

Fuzzy models are useful in handling imprecise and vague data, which are common in the textile and apparel industries where consumer preferences can be highly subjective. Furthermore, robust optimization is applied in industries like healthcare equipment and
supplies, where the consequences of supply chain failures can be severe. This approach ensures that solutions remain effective under a wide range of conditions.

By examining the connection between modeling approaches, solution methods, and their applications in specific industries, we can identify patterns and best practices. For instance, in the automotive industry, the use of MILP and robust optimization techniques is common due to the need for precise optimization and resilience against supply chain disruptions. In the food products industry, stochastic programming and fuzzy models are frequently employed to manage the high levels of uncertainty and perishability.

Geographic location also plays a role in the choice of modeling approaches. In regions with stringent environmental regulations, such as Europe, models often incorporate environmental indicators and robust optimization techniques to comply with regulatory requirements while ensuring sustainability. In contrast, in regions with rapidly growing markets, such as Asia, models may focus more on scalability and flexibility to adapt to changing market conditions.

By integrating these elements into a cohesive framework, we can develop more effective CLSC models that are tailored to the specific needs of each industry and location. This holistic approach ensures that supply chains are not only efficient and resilient, but also sustainable and adaptable to future challenges.

Lastly, the connection between applications, case locations, modeling approaches, and solution methods is crucial for developing effective CLSC models. By understanding how these elements interact, we can create tailored solutions that address the unique challenges of each industry and region. This integrated approach enhances the overall efficiency, sustainability, and resilience of supply chains.

4.7. Uncertainty

Uncertainty significantly impacts the effectiveness of network design in SCM. Real-world applications often see small data perturbations rendering solutions suboptimal or infeasible [96,97]. Uncertainties can stem from internal organizational factors (like manufacturing processes), internal SC issues (such as demand and supplier configurations), and external factors (including environmental and macroeconomic issues) [98].

SC network design, involving long-term strategic decisions and substantial investments, must account for uncertainties in critical parameters like demand, costs, and returned products.

Recent research has focused on inexact methodologies to address decision-making uncertainties in SC design. These include stochastic programming, fuzzy programming, and robust optimization programming. Stochastic programming is effective when credible historical data are available, but its limitations include fitting probability distributions, potential infeasibility, and computational complexity in large-scale problems [99,100].

Employing fuzzy numbers is beneficial for encompassing uncertainty and ambiguity. However, it is important to acknowledge that various factors within the workplace may influence the conditions and fundamental parameters of problems. Fuzzy programming is a method that tackles uncertainties in situations where decision makers do not have exact information. It incorporates fuzzy sets into traditional programming to effectively manage imprecise circumstances [101,102].

The robust optimization approach is widely recognized as an effective strategy for managing uncertainty. Robust optimization, initially offering conservative solutions, has evolved to reduce conservatism [103]. Furthermore, implementing robust optimization models is essential for managing uncertainties and ensuring the continuity of supply chains under crisis conditions. For example, Mahdavimanshadi et al. [104] developed a multi-stage stochastic optimization model tailored to enhance the resilience of pharmaceutical supply chains during the pandemic, emphasizing patient group priority. Soyster [105] first addressed uncertainty within a convex set for linear optimization [105]. Later, researchers like El-Ghaoui, Lebret [106], Ben-Tal, Nemirovski [107], and Bertsimas, Sim [108] refined robust optimization to balance robustness with reduced conservatism. Also, in [109], robust
optimization is utilized to cope with the operational uncertainty of some cost parameters in the integrated production–distribution planning of perishable goods, ensuring a more reliable SC performance.

CLSCs supply chains aim to integrate the forward and reverse flows of products to minimize waste, enhance sustainability, and improve overall efficiency. To achieve these goals, it is crucial to define and optimize stability parameters and objective functions within CLSC models.

Stability parameters are essential for ensuring the resilience and robustness of CLSCs in the face of various uncertainties. These parameters help maintain the balance and performance of the supply chain under different conditions. Key stability parameters include demand variability, supply disruptions, lead times, return rates, and quality degradation. Demand for perishable goods can fluctuate due to seasonal changes, market trends, and consumer preferences. Stability parameters must account for these variations to ensure a consistent supply of products without overproduction or stockouts. Factors such as natural disasters, political instability, and logistical challenges can disrupt the supply of raw materials or finished goods. Stability parameters help in developing contingency plans and alternative sourcing strategies. The time taken for products to move through the supply chain, from raw material procurement to final delivery, can impact the freshness and quality of perishable goods. Stability parameters ensure that lead times are minimized and optimized for efficiency.

In a CLSC, managing the return flow of products is as important as the forward flow. Stability parameters help predict and manage return rates, ensuring that returned products are efficiently processed, remanufactured, or recycled. Perishable goods are prone to quality degradation over time. Stability parameters must include measures to monitor and maintain product quality throughout the supply chain.

The most used parameters and variables uncertain are as follows:

Customer Demand [98,110,111], Return Quantities [112,113], Costs [114,115], Capacity [116,117], Return Qualities [118,119], Price [111], Lead and Throughput Times [120], Risks [98,121], Disposal Rate [122], Wastage generation [123,124], Supply [38,125], Collection rate [126,127], Manufacturing Rate [98], Carbon Emissions [128,129], Material flow [123], Distance between facilities [130,131], Transportation mode selection [132,133], Flexibility [134,135], Facility location [131,136], and Supplier selection [137,138].

Various modeling approaches have been developed to address different types of uncertainties, including demand variability, return rates, and supply disruptions. Here, we illustrate how different modeling approaches are applied in real-world case studies and the outcomes which are achieved.

For instance, in the automotive industry, a stochastic programming model has been used to optimize the CLSC of remanufactured auto parts. The study by Amin and Zhang [139] demonstrated how this approach minimized costs and environmental impact under uncertain demand and return rates. The model’s flexibility allowed the company to adapt to fluctuations in both market demand and the quantity of returned products, ensuring a steady supply of remanufactured parts. In another example, in the pharmaceutical sector, robust optimization was applied to design a CLSC for the distribution of medicines. Pishvavee, Rabbani, and Torabi [100] implemented this approach to manage the uncertainties in supply lead times and demand, resulting in a robust supply network that maintained service levels despite disruptions. This method ensured the continuous availability of critical medications, highlighting its efficacy in a highly regulated and sensitive industry.

Ramezani et al. [68] utilized fuzzy logic to manage the CLSC of fresh produce. The model accounted for the perishability and quality degradation over time, addressing the uncertainties in supply quality and consumer demand. By incorporating fuzzy sets, the model improved the freshness of products delivered to customers and reduced waste significantly. In the electronics industry, a hybrid model combining stochastic and fuzzy programming was developed to manage the CLSC of returned consumer electronics. Dehghan et al. [140] showed that this approach effectively balanced cost, environmental impact, and service
levels by addressing the uncertainties in return rates and demand variability. The hybrid model provided a more resilient and adaptive supply chain compared to using a single method.

5. Perishable Products

Perishable products, ranging from fresh food and newspapers to hotel rooms, are crucial in many industries [141]. A product is considered perishable if its quality or quantity deteriorates noticeably, its reduced functionality has severe consequences, or its value decreases over time [142]. Research in this area includes studies on perishable foods like seafood [143], dairy products [144], and fruits and vegetables [145].

Companies like Walmart face challenges in managing perishables, which form a significant part of their inventory, including food, pharmaceuticals, chemicals, and cut flowers [146]. Findings indicate that standard cost parameters in order policies often lead to poor product quality and high waste. Incorporating shelf life loss costs into sourcing strategies can reduce waste and improve quality, but may increase transportation costs. This necessitates a balance between transportation, shortage, inventory costs, product waste, and expected shelf life losses in the SC design of perishable products [147].

The challenge with perishables is their quality and value degradation over time, even with proper handling. With rising living standards, consumers increasingly prefer high-quality fresh foods over non-perishable items. For instance, in the U.S. grocery industry, perishable foods make up 50% of sales, significantly impacting grocers’ revenue and costs [148,149]. Managing perishables involves trade-offs, such as between cost and batch size in SCs, to minimize value loss; thus, the optimal batch size depends on balancing the cost of time delays against the value loss during storage and transportation [150].

Perishability impacts various sectors. In healthcare, the perishable nature of organs affects transplants; in pharmaceuticals, the chemical composition dictates medicine efficacy, and blood bank management in hospitals is vital. The agri-food sector is particularly affected; dealing with frequent complexity often requires heuristic approaches for optimization due to computational challenges.

Effective management in this sector relies on real-time information sharing to balance service levels and cost minimization. Coordination gaps in food SCs can lead to unharvested produce upstream and unsold products downstream, resulting in waste, increased costs, and pollution from additional transport [151]. Furthermore, it is worth noting that revenue management involves effectively controlling the sale of a limited quantity of resources to potential customers. Equilibrium strategies can empower sellers of perishable, limited-capacity goods to maximize their profits [152].

Furthermore, many inventory models studied by researchers are predicated on the notion that inventory items can be kept indefinitely until demand is met. Spoilage is a common occurrence in the real world, indicating that the product has deviated from its expected performance. If corruption cannot be ignored, it must be modeled.

The majority of studies on perishability predominantly focus on the inventory management of perishable products. Generally, inventory items can be classified into three types, each with distinct characteristics and challenges:

First, products with unlimited shelf lives represent a significant portion of inventory models. These models often assume that products can be stored indefinitely without any loss in value or functionality. This assumption simplifies inventory management but does not apply to all types of products.

Second, obsolete products refer to items that lose their value over time due to rapid technological advancements and the emergence of new products from competitors. These goods must be sold at a much lower price or disposed of after the sale season has ended. Managing inventory for obsolete products requires strategies to minimize losses and make timely decisions about markdowns and disposal.

Third, perishable products, such as many types of food, pharmaceuticals, chemicals, and blood, present unique challenges. Perishability encompasses all kinds of damage,
waste, drying, and evaporation, leading to the product losing its function. The management of perishable products has been a compelling research topic, as spoilage significantly impacts decision-making processes. The field has seen continued interest and development because the spoilage of products often influences policies and ordering decisions.

Research on perishable product inventory systems examines various aspects, including the optimal order quantities, storage conditions, and shelf life management strategies. Effective management of these products is crucial, as spoilage can lead to significant financial losses and waste. Consequently, policies that address the specific needs of perishable goods are vital for maintaining product quality and reducing losses [153].

Thus, it can be mentioned that the study of perishable product inventory systems remains a dynamic and essential area of research, driven by the significant impact of product spoilage on inventory management and decision making. By understanding and addressing the unique challenges of perishable products, companies can develop more effective strategies to manage their inventories and minimize losses.

5.1. Perishability Types

SCM for perishable items is complex and time-sensitive [154,155]. The literature primarily categorizes perishable items into two types: (i) fixed-lifetime and (ii) age-dependent. Fixed-lifetime items, like dairy products and pharmaceuticals, have a specific expiration date after which they are no longer usable. Age-dependent items lead to small orders, tight delivery windows, and uncertainties in yield and demand. Over time, this causes them to lose value, and their expiration date is not pre-set [156,157]. Agricultural products are an example.

Generally, foodstuffs, vegetables, human blood, photographic film, drugs and chemicals, electronic goods, radioactive materials, and volatile liquids are among the goods that perish during their storage period, and therefore, it is necessary to include the phenomenon of perishability in the model. Their inventory should be taken into account [158].

Meanwhile, groups of products such as milk and vegetables or bread have a fixed life and can be consumed until the end of their life. However, from the consumers’ point of view, as these products age, they become less desirable and are valued less in terms of purchase price. In essence, the price of these products is influenced by their remaining shelf life. This category of materials is called time-dependent perishable materials. This type of price reduction is a standard method in supermarkets to sell goods nearing the end of their life [159].

The research on handling perishable goods in SCs encompasses various approaches, focusing on factors such as fixed shelf life, deterioration over time, and these factors’ economic and environmental impacts. In the following section, you can find a synthesis review of some of these critical studies in the field:

In the context of costs and shelf life management, AriaNezhad et al. [160] integrated costs related to perishables in warehouse settings into their objective function. This integration highlights the economic implications of managing perishable goods effectively. Similarly, Bortolini et al. [25] employed a function to assess the likelihood of market purchases which takes into account the decline in product quality over time, emphasizing the importance of timely market decisions. Amorim et al. [161] advanced this field by devising two models for fixed and variable shelf life scenarios, with the latter incorporating predictive microbiology and storage temperature. This dual approach allows for more accurate predictions of product longevity [145]. Further, Seyed Hosseini and Ghoreyshi [162,163] developed optimization models for perishables with both fixed and variable lifespans, including a quality loss in inventory costs. These models underscore the necessity of accounting for quality degradation in inventory management. Additionally, Aazami and Saidi-Mehrabad [164] developed a multi-period production–distribution planning model for perishable products with fixed lifetimes within a vertically competitive seller–buyer system, illustrating the competitive dynamics involved in perishable goods markets.
In the field of inventory and product age, a study [156] defined a discrete set for product age, analyzing its effects on revenue and inventory holding costs, particularly for items prone to deterioration. This discrete approach provides a framework for understanding how product aging impacts economic outcomes. Rahimi et al. [165] proposed a stepwise nonlinear holding cost to manage non-fresh products, balancing economic, service level, and environmental considerations. This balance is crucial for maintaining sustainability while managing costs. Moreover, Biuki et al. [155] considered the shelf lives of both raw materials and finished products in their MILP model, showcasing the complexity of managing perishable inventories.

Some studies have explored the impact of packaging on shelf life, indicating that innovative food packaging can significantly lengthen the expiration dates of products, thereby lowering the decay rate [166–168]. This innovation is key to extending product usability and reducing waste.

Research in food supply chains often employs a quality level index to track food quality and its influence on prices and demand. For example, Chao et al. [169] focused on deterioration due to transport time and disruptions, such as frequent door openings in trucks, which directly affect food quality. Ahumada and Villalobos [170] examined the value loss in agricultural products post-harvest, using a color function to predict product quality, thereby providing a practical tool for quality assessment. Similarly, Mirzaei and Seifi [171] addressed deterioration by correlating lost sales with inventory age, highlighting the financial impacts of product aging.

Accorsi et al. [172] considered various shelf life values and quality decay, referencing kinetic models like the Arrhenius equation and accelerated aging factors. These models provide a scientific basis for understanding and predicting product deterioration. Some models use time-dependent deterioration rates, such as those studied by Onggo et al. [173], who accounted for different degradation speeds in products. This variability in degradation rates underscores the need for tailored management strategies. Additionally, Manoucheri et al. [174], utilizing the Gompertz equation (Gil, Miller, Brandao, and Silva, [175]), estimated microbial growth in perishable goods, providing insights into the biological processes affecting product shelf life.

Collectively, these studies provide a comprehensive understanding of the complexities of managing perishable goods in supply chains. They highlight the importance of integrating various factors such as shelf life, deterioration rates, packaging, and environmental impacts into the decision-making process.

5.2. Sustainability for Perishable

Sustainable SCM, which has attracted the attention of various companies today, pays particular attention to the three dimensions of the environment, society, and economy in such organizations. In recent decades, organizations have needed to manage and increase customers, etc., to be able to maintain themselves in the field of competition. Perishable products are an attractive area for research in the field of sustainable SCs since they directly affect three factors of sustainability (environment, society, and economy). Furthermore, with increasing urgency in limiting greenhouse gas and carbon dioxide emissions, perishable food logistics activities have become an issue of concern.

Sustainability in the context of perishable products, particularly within food SCs, presents a complex and multifaceted challenge. Recent studies have highlighted various critical aspects:

- Focusing solely on cost in the supply chain of highly perishable commodities can significantly amplify environmental impacts. Abbas [176] found that emphasizing cost factors alone can increase the environmental impact by as much as 108% for perishable goods. This finding underscores the need to balance cost considerations with environmental responsibility. Managing perishable food supply chains is particularly challenging due to the short lifespan of products and demand uncertainty. Zhu [177] discussed the difficulties posed by the deterioration rate and the unpredictability of demand in managing
these supply chains. These challenges necessitate robust strategies to handle the inherent volatility and ensure supply chain efficiency.

Jouzdani [178] emphasizes that considering all aspects of sustainability—economic, environmental, and social—is crucial for food supply chains. This holistic approach is essential for effectively managing perishable food SCs, ensuring that sustainability is integrated into every facet of the supply chain. The variability in the lifetimes of perishable foods is another critical factor. Abbas [176] notes that this variability can be modeled using the Weibull random approach, which is vital for planning and managing these supply chains. Accurate modeling helps in developing strategies to mitigate the impacts of this variability, thereby enhancing supply chain resilience.

Quality and safety concerns are rising in perishable food supply chains, along with alarming levels of food waste and loss. Kumar [179] highlights these issues, stressing the importance of addressing them to ensure the sustainability of perishable food SCs. Ensuring high standards of quality and safety is paramount to reducing waste and maintaining consumer trust. Finally, food waste in perishable products is driven by various factors, including production methods, regional practices, lifestyle, industrialization, and consumer acceptance. Addressing these factors is vital for achieving sustainability in perishable food supply chains. Effective strategies must be developed to tackle these underlying causes of food waste [180].

These insights collectively highlight the need for a comprehensive and integrated approach to managing perishable food supply chains, balancing cost, sustainability, and the unique challenges posed by perishability.

6. Perishables and CLSC Literature Analysis

6.1. Bibliometric Analysis

The landscape of CLSC management, particularly for perishable products, is a vibrant and rapidly evolving field of study. An examination of the literature, as illustrated in the provided figures, reveals a trajectory of increasing scholarly attention. This surge in research interest from 2017 to 2023 suggests an academic and industrial awakening to the complexities and critical importance of sustaining a closed-loop system in the perishable goods sector. Factors such as heightened environmental concerns, technological advancements, and consumer behavior shifts have been pivotal in propelling this scholarly momentum. The review of such literature is not just an academic exercise; it serves as the compass guiding the future of sustainable SC practices. It stands at the intersection of environmental stewardship and SC innovation, demanding our focus and continued inquiry.

As illustrated in Figure 4, the number of publications on CLSC has shown a consistent upward trend from 2017 to 2023. This increase can be attributed to several factors:

First of all, the growing global emphasis on sustainability has driven research interest in closed-loop systems, which are seen as vital for reducing waste and promoting resource efficiency. This trend is reflective of the increasing global commitment to the United Nations Sustainable Development Goals (SDGs), particularly Goal 12, which focuses on responsible consumption and production.

Furthermore, innovations in technology, such as the Internet of Things (IoT) and artificial intelligence (AI), have enabled more sophisticated modeling and management of supply chains, making research in this area more feasible and impactful. These technologies facilitate real-time data collection and analysis, which are critical for managing the complexities of perishable goods in a CLSC.

Moreover, stricter environmental regulations and policies have incentivized companies to adopt CLSC practices, spurring academic research to support these efforts. Policies such as the European Union’s Circular Economy Action Plan and various national regulations on waste management and recycling have created a favorable environment for the adoption of CLSCs.
These insights collectively highlight the need for a comprehensive and integrated approach to managing perishable goods. It depicts an upward trend in the number of publications from 2017 to 2022, with a slight decrease in 2023. The increase in publications over the years indicates a growing interest in and relevance of SCM for perishable goods. This could be due to increased consumer awareness, stricter regulations on food waste, or technological advances that enable better management of perishables.

The peak in 2022, followed by a slight decline in 2023, could suggest a saturation point in research or a shift in focus within the field. It is also possible that external factors, such as global events or economic conditions, have influenced research outputs. The data underscores the importance of conducting a timely literature review. With the most recent research included, the review can provide an updated synthesis of knowledge, practices, and trends in managing perishable SCs.
This can help us to understand which regions are leading in research and implementation, visually represents the geographic distribution of research and interest in perishable SCM. For example, countries that are major producers of perishable goods may have more publications due to the necessity of efficient SCM.

**Figure 5.** The distribution of various types of documents from 2017 to 2023, based on “closed AND loop AND supply AND chain”.

**Figure 6.** The number of documents published each year from 2017 to 2023, based on “supply AND chain AND perishable”.

Figure 7 is a global map with countries shaded in different colors, likely representing the frequency of publications related to “supply chain” and “perishable” topics. The map visually represents the geographic distribution of research and interest in perishable SCM. This can help us to understand which regions are leading in research and implementation,
potentially indicating where the most advanced practices might be found. It highlights countries or areas with significant research output, possibly due to specific regional challenges or advances. For example, countries that are major producers of perishable goods may have more publications due to the necessity of efficient SCM.

![Figure 7](image_url)

**Figure 7.** The frequency of publications related to the supply chain for perishables from 2017 to 2023.

Notably, countries with significant agricultural and industrial activities, such as the United States, China, Iran, and European nations, dominate the research landscape. This geographic distribution reflects the regions where supply chain management for perishable goods is most critical due to the scale of production and consumption. Additionally, these regions often have advanced research institutions and funding mechanisms that support extensive research activities.

The U.S. leads in research output, likely due to its large agricultural sector and strong emphasis on sustainability in both academia and industry. Institutions like MIT, Stanford, and others have been at the forefront of supply chain and sustainability research. On the other hand, rapid industrialization and urbanization in China have led to increased research in sustainable supply chain practices. Chinese institutions are heavily involved in research due to governmental policies promoting sustainability.

With 358 publications, Iran is also a significant contributor to the research landscape. The country has a substantial agricultural sector and faces unique challenges in managing supply chains for perishable goods. Iranian researchers have focused on developing efficient and sustainable practices tailored to the region’s specific conditions. The emphasis on sustainability in Iran’s research can be linked to both the necessity of optimizing resource use in arid climates and the increasing national focus on environmental conservation. European countries, driven by stringent environmental regulations and a strong emphasis on the circular economy, also contribute significantly to the research output. The presence of collaborative frameworks like Horizon 2020 has facilitated numerous research projects across European institutions.

The map can point towards potential collaborations by identifying the countries with high levels of research activity. These regions could be hubs for academic institutions or industries specializing in the field, providing opportunities for knowledge exchange and
partnerships. Additionally, by showing where research is lacking, the map can also indicate potential gaps in knowledge or practice. This could help identify areas for future research, particularly in terms of developing closed-loop systems for perishable goods. The map reflects where perishable supply chains’ most significant environmental impacts occur. In closed-loop systems, understanding the geographical distribution of these impacts can be crucial for designing interventions that reduce waste and emissions. Finally, the map allows for a comparative analysis of research intensity across countries. This leads to insights into the reasons behind these differences, such as economic development, climatic conditions, or technological capabilities.

In Figure 8, “supply AND chain AND perishable” is used in a search within the SCOPUS database. Based on this result, R. Accorsi has the highest number of publications related to the SC of perishable goods, which indicates a significant contribution to the body of knowledge in this area. These researchers have collectively addressed various aspects of CLSC, including economic modeling, environmental impact assessments, and the application of new technologies to enhance supply chain performance.

![Figure 8. The top 10 authors in terms of publication quantity within the SCOPUS database.](image)

### 6.2. Current Research on CLSCs for Perishable Products

The present study reviews recent perishable CLSC studies from 2017 to 2023. To ascertain the current state of perishable CLSC research and establish objectives for the subsequent investigations, a review of the relevant literature is conducted in this work. Table 5 presents the result of the review.

In this table, a comprehensive literature review table is presented. It consolidates a vast amount of research into an easily digestible format, allowing readers to quickly understand the landscape of current research on CLSCs for perishable products. It also provides a quick reference for other researchers to identify relevant studies, their methodologies, and their applications, which can aid in further research or implementation. By listing the purposes and models used in various studies, gaps in the research, such as underexplored objectives, industries, or solution methods, are identified. This table reveals trends in research focus, modeling techniques, and solution approaches over time, which is valuable for understanding the field’s evolution.

This literature review considers only optimization-based approaches to CLSC. By applying this methodology, the review seeks to provide an in-depth review of the state of the field of perishable CSC research, point out knowledge gaps, and define clear recommendations for future research endeavors. These articles are classified and listed according to the authors, years, purposes, model formulation, solution approach, and industries. Moreover, Figure 9 illustrates the co-authorship network of Table 5.
Figure 9. Co-authorship network of authors with a minimum of one publication.

Figure 9 illustrates the co-authorship network of authors with at least one publication on CLSC for perishables. This network analysis provides insights into the collaborative patterns and influential researchers within the field. The network highlights central authors like Mostafa Hajjahghaei-Keshteli, Amir Mohammad Fathollahi-Fard, and Mohammad Yavari. These researchers are pivotal in the field, as indicated by their extensive collaborations with various other authors. Their central position in the network suggests that they are key influencers and major contributors to the research on CLSC. The network is divided into several clusters, each representing a group of researchers who frequently collaborate. The network also shows interdisciplinary collaborations, where researchers from different fields or institutions come together to address the complex challenges of CLSC. These collaborations are crucial for integrating diverse expertise and advancing the field.

Figure 10 details the distribution of product types discussed in the reviewed articles in the table. The chart segments indicate the relative frequency with which each product type is mentioned. This explains the research focus within the CLSC for perishable products literature. Tires and dairy: Researchers have emphasized tires and dairy products the most, likely due to their significant environmental impact and the challenges associated with managing their supply chains.

Figure 10. Frequency of products in the reviewed articles.
Table 5. Reviewed articles on CLSCs for perishable products.

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<th>No.</th>
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<th>Solution Approach</th>
<th>Industry</th>
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<td>GAMS</td>
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<td>46</td>
<td>[223]</td>
<td>2022</td>
<td>Profit and social welfare</td>
<td>MILP</td>
<td>Two-stage Stackelberg game</td>
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<td>47</td>
<td>[224]</td>
<td>2023</td>
<td>The reaction time demands</td>
<td>MILP</td>
<td>Meta-heuristic and hybrid algorithms</td>
<td>Fish</td>
</tr>
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<td>48</td>
<td>[225]</td>
<td>2023</td>
<td>Cash flow</td>
<td>MILP</td>
<td>ABD algorithm and WSM augmented ε-constraint and FMOP</td>
<td>Dairy</td>
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<td>49</td>
<td>[226]</td>
<td>2023</td>
<td>***</td>
<td>NLP</td>
<td>Generalized reduced gradient</td>
<td>Pharmaceutical</td>
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<td>50</td>
<td>[227]</td>
<td>2023</td>
<td>Environmental and social cost</td>
<td>MILP</td>
<td>Augmented ε-constraint</td>
<td>Tire</td>
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<td>51</td>
<td>[228]</td>
<td>2023</td>
<td>Profit and customer satisfaction</td>
<td>MILP</td>
<td>(MOGWO_SA) and (MOKA_SA) and (MOHHO_SA) and (MOSA)</td>
<td>Agri-food</td>
</tr>
<tr>
<td>52</td>
<td>[229]</td>
<td>2023</td>
<td>***</td>
<td>MILP</td>
<td>Six new multi-objective evolutionary algorithms based on decomposition (MOEA/D) variants</td>
<td>Tire</td>
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Note: 2 Multiple-criteria decision making; 3 Whale optimization algorithm; 4 Multi-Objective Particle Swarm Optimization; 5 interval chance-constraint mixed-integer nonlinear programming; 6 differential evolution algorithm; 7 Multi-Choice Goal Programming Approach with Utility Function; 8 Lagrangian relaxation method; 9 constructive heuristic algorithm; 10 Multi-Objective Evolutionary Algorithm; 11 fuzzy multi-objective programming; 12 Multi-Objective Gray Wolf Optimizer and Simulated Annealing; 13 Multi-Objective Keshtel Algorithm and Simulated Annealing; 14 Multi-Objective Harris Hawks Optimization and Simulated Annealing; 15 Multi-Objective simulated annealing. *** shows information not provided or not applicable.
Perishables: The frequent mention of perishables like fruits, vegetables, and pharmaceuticals underscores the critical need for efficient and sustainable supply chain practices for products with limited shelf lives.

In Figure 11, a donut chart displays the various modeling approaches used in the studies included in the review. Dominating the chart with 61%, MILP is the most frequently used model formulation, indicating its popularity or suitability for solving CLSC problems. Also, MILP’s flexibility in handling various constraints and objectives makes it a preferred choice for researchers.

![Model Formulation](image)

**Figure 11.** Model formulation.

Other approaches, the diversity in modeling approaches, including stochastic programming and fuzzy optimization, highlight the complexity of CLSCs and the need for sophisticated methods to address uncertainties and multi-objective optimization.

Overall, both charts provided are critical for understanding the current landscape of our review. The first figure highlights the industries receiving the most attention, while the second figure showcases the range of analytical techniques researchers apply to these problems. Together, they provide a comprehensive overview of where the focus of current research lies and where there may be opportunities for new studies to contribute to the field.

Thus, the thorough literature analysis underscores a clear trajectory toward sustainability and efficiency in managing perishable supply chains. The growing corpus of research encapsulates a wealth of knowledge, methodologies, and practical applications that illuminate the path forward. However, it also reveals gaps and areas ripe for further exploration. As we synthesize this body of work, we understand that CLSC management for perishables is not just a topic of academic interest, but a critical enterprise with significant implications for the environment, economies, and societies globally. Researchers and practitioners are equally responsible for expanding on this groundwork, innovating, and adjusting to accommodate the needs of a swiftly evolving global landscape.

### 6.3. Detailed Evaluation of Methodology

The following sections will discuss the in-depth strengths and weaknesses of the methodology, providing a comprehensive evaluation of its effectiveness and limitations.

In terms of strengths, the methodology of this review article is notable for its comprehensive literature review, which employs a structured and extensive approach. By leveraging multiple academic databases such as Scopus, Web of Science, and Google Scholar, the review ensures a broad and inclusive collection of sources, enhancing both the robustness and the depth of the analysis. One of the key strengths is the clear selection criteria outlined for the sources, which include publication date, relevance, and quality.
This methodical filtering process helps in focusing on high-quality and pertinent studies, ensuring that the review is concentrated on recent advancements and trends in the field.

The hierarchical structure of the review is another strength, as it systematically explores the integration of perishable products into CLSCs. This structured approach ensures a thorough analysis of concepts fundamental to specific applications, effectively identifying gaps in the current research. Conducting a bibliometric analysis to quantify the research landscape adds significant value. This analysis provides a clear picture of publication trends, key authors, and the geographic distribution of research, adding a quantitative dimension to the qualitative review and enhancing its credibility. The inclusion of a comprehensive literature review table that summarizes key studies, models, solution methods, and industries is particularly beneficial. This table serves as a quick reference for researchers and practitioners, facilitating the identification of relevant works and methodologies.

The review’s focus on perishability is crucial given the complexity and importance of managing perishable goods in supply chains. By discussing the types of perishability, handling, and logistics strategies, the review addresses a critical aspect of CLSCs that is often challenging to manage.

Despite its strengths, the methodology has some weaknesses. There is a potential bias in source selection, as the clear selection criteria might inherently favor well-known journals and conferences. This could lead to the exclusion of valuable insights from less prominent sources or those published in non-English languages. The review’s focus predominantly on optimization-based approaches to CLSC may overlook other valuable methodologies such as simulation, empirical case studies, or qualitative analyses. These alternative approaches could provide additional insights and a more holistic view of the challenges and solutions in integrating perishables into CLSCs.

Another limitation is the over-reliance on secondary data. The methodology heavily relies on existing literature, which may limit the originality of the findings. Incorporating primary data collection methods, such as surveys or interviews with industry practitioners, could enhance the empirical grounding of the review. The complexity in data synthesis is also a concern. The hierarchical structure and extensive scope might make synthesizing data complex and challenging, potentially leading to difficulties in maintaining a coherent narrative and drawing clear conclusions from a large volume of diverse studies.

There is also limited geographic and sectoral diversity. Although the review includes a bibliometric analysis, the selected studies might still reflect a concentration in certain geographic regions or sectors, potentially limiting the generalizability of the findings to other contexts. Lastly, the methodology may insufficiently address practical implementation challenges. While emphasizing theoretical and optimization models, it might not adequately cover the practical difficulties of implementing CLSC models for perishable products in real-world settings. Including more case studies or practical examples could provide a better balance between theory and practice.

7. Research Gaps and Future Agendas

Our review uncovers various research gaps pivotal for advancing scholarly understanding and practical implementation of sustainable supply chain management (SCM). Although CLSCs are acknowledged for enhancing environmental sustainability and offering economic benefits through integrated processes such as collection, remanufacturing, and recycling, the complexity of managing perishables within these systems presents distinct challenges.

A significant gap lies in the tendency of existing literature to prioritize single-objective functions, like cost minimization, over a multifaceted approach that simultaneously addresses cost, quality, and sustainability. This overlooks the interdependence of these factors and the need for a holistic approach to optimize them collectively. Furthermore, the incorporation of customer-centric metrics into objective functions is notably sparse. Given the perishable nature of the products, aligning supply chain processes with customer satisfaction and behavior is crucial, yet often neglected in research.
The significance of community participation and education in supply chain management becomes evident when considering the broader societal implications of fair-trade practices, labor conditions, and environmental impact. Engaging the community in understanding the value of sustainable supply chain practices is crucial for creating a more comprehensive and inclusive approach to supply chain management. By cultivating partnerships with local communities, implementing educational programs, and raising awareness through targeted outreach efforts, we can bridge the gap between supply chain operations and the community, fostering a collective effort towards sustainable and socially responsible supply chain systems [230].

Research gaps extend to integrating objectives aimed at combating climate change. Despite the urgency of reducing carbon footprints and improving energy efficiency, the literature does not reflect these as priority objectives. The potential of cutting-edge technologies like IoT and AI for real-time data utilization in SCM is another underutilized area, indicating a gap in leveraging technological advances to transform supply chain operations for perishables.

Waste reduction is a crucial concern for perishable goods, yet comprehensive waste reduction objectives spanning the entire supply chain are not sufficiently quantified. Regulatory compliance, particularly concerning food safety and environmental impact, often does not feature prominently in supply chain models. Life cycle analysis, considering the effects from production to disposal, is rarely positioned as a focal point in research. Additionally, the literature does not adequately explore the collaborative potential across all supply chain stakeholders, which is essential for collective efficiency and performance improvement.

Moreover, the impact of demand fluctuations, known as the bullwhip effect, on sustainable supply chains for perishable items is minimally researched, highlighting the need for future studies on controlling such volatility. Inventory management’s complexity, particularly in reverse logistics, and the integration of production routing within CLSCs are also identified as minimally explored areas. Strategic and tactical decisions in supply chain network design, such as facility location and risk management, especially regarding operational and disruption risks, are further areas calling for advanced research.

A notable research gap is the integration of insights from other disciplines, such as biology, chemistry, and data science, into the management of perishables in CLSCs. Future research should explore how interdisciplinary approaches can enhance the efficiency and effectiveness of perishable goods management. Additionally, while the potential of IoT and AI has been acknowledged, the application of blockchain technology for improving transparency, traceability, and trust in perishable goods CLSCs remains underexplored. Future studies should investigate how blockchain can be integrated into CLSCs to enhance data security and traceability of perishable products.

The current literature often overlooks dynamic pricing strategies that account for the perishability and varying demand of goods. Research should focus on developing dynamic pricing models that optimize profits while minimizing waste and enhancing customer satisfaction. There is also limited research on how consumer behavior and preferences impact the efficiency of CLSCs for perishables. Future research should incorporate behavioral economics to understand consumer choices and their effects on supply chain dynamics.

The impact of climate change on the production, transportation, and storage of perishables is an area needing more attention. Research should focus on developing adaptation strategies that can mitigate the adverse effects of climate change on perishable goods supply chains. Additionally, small-scale farmers often struggle to integrate into large CLSCs due to technological and logistical barriers. Future studies should explore how to better incorporate small-scale producers into CLSCs, ensuring that they can participate in and benefit from sustainable supply chain practices.

Moreover, more research is needed on innovative business models that fully embrace circular economy principles for perishables, including models that emphasize product life cycle extension, reuse, and recycling within perishable goods supply chains. The use of advanced predictive analytics for demand forecasting and inventory management...
The role of policies and regulations in shaping sustainable CLSCs for perishables needs further examination. Research should investigate how different regulatory frameworks impact the efficiency and sustainability of these supply chains and propose policy recommendations to support sustainable practices. While the environmental benefits of circular practices are well-documented, their economic impacts, especially in the context of perishables, are less studied. Future research should quantify the economic benefits and costs associated with implementing circular practices in CLSCs for perishables.

By addressing these gaps, future research can contribute to a more comprehensive understanding and improvement of CLSCs for perishable goods, ultimately leading to more sustainable, efficient, and resilient supply chains.

8. Conclusions

The CLSC management field, especially in the context of perishable products, has seen a remarkable surge in scholarly and industrial interest. This increasing attention is a testament to the growing recognition of the complexities and the pivotal role of closed-loop systems in the sustainable management of perishable goods. Key factors driving this academic and industrial awakening include heightened environmental concerns, technological advancements, and significant shifts in consumer behavior. These elements have been instrumental in propelling the momentum in research and practice within this domain.

Our comprehensive review of the literature serves not only as a scholarly endeavor, but also as a guiding beacon for the future of sustainable SC practices. It occupies a critical intersection where environmental stewardship converges with innovative SCM. This review underscores the importance of continuing to focus on and inquire into this evolving field.

The observed trend of increasing document publications from 2017 to 2023, as depicted in the accompanying figures, further emphasizes the escalating relevance of CLSC management in both academic and industry circles. This trend may be attributed to a broader recognition of the need for sustainability and efficient resource utilization, which are fundamental components of CLSCs. The growing volume of research highlights the necessity of an in-depth review of the existing literature to integrate these concepts thoroughly into mainstream SCM, synthesize the current knowledge, and identify gaps for future exploration.

In conclusion, the evolving landscape of CLSC management, particularly for perishable products, presents a dynamic and vital area for ongoing research and implementation. The field stands at a crucial juncture, demanding dedicated focus and continuous scholarly inquiry to drive forward sustainable practices in SCM. The increasing body of literature reflects the growing importance of this field. It provides a wealth of knowledge for future investigations, paving the way for innovative solutions and sustainable practices in the perishable goods sector.

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