Metaheuristics in Circular Supply Chain Intelligent Systems: A Review of Applications Journey and Forging a Path to the Future

Abstract

Metaheuristics have become increasingly popular due to the complex and extensive optimization models that have emerged in the circular supply chain field. This study aims to fill a gap in the literature by conducting a comprehensive analysis of the role of metaheuristics in reverse logistics and circular supply chains. The methodology involves a meticulous review of 77 meticulously selected research articles published until 2023. The findings of our analysis indicate a significant increase in the number of publications in recent times. Through descriptive and content analyses, key themes emerge, including types of metaheuristics used, addressed supply chain issues, and circularity aspects. This study presents a novel approach to analyzing the application of metaheuristics from a circularity perspective. It also introduces a conceptual framework and suggests cluster-based future research directions. The results of the study hold valuable implications for researchers and other stakeholders in terms of understanding and advancement of the field.

Keywords: Metaheuristics; circularity; reverse logistics; closed-loop supply chain; systematic literature review; conceptual framework.

1. Introduction

The circularity notion has significantly impacted the realm of sustainability, capturing attention for its involvement in the creation of closed-loop systems that effectively minimize waste and optimize the utilization of resources (Simonetto et al., 2022). This approach has garnered attention in recent years as the world grapples with the climate crisis and the need for sustainable development becomes more pressing (Fathollahi-Fard et al., 2023a; Homayouni et al., 2023). As per a report[1] published by Precedence Research, "The global waste recycling services market was valued at 55.1 billion U.S. dollars in 2020 and was estimated at 57.69 billion U.S. dollars in 2021. The market is expected to grow considerably in the coming years as consumer awareness about the environmental impacts of waste increases." Metaheuristics, a set of optimization algorithms influenced by nature, have emerged as a promising avenue for designing circular systems (Goodarzian et al., 2023). In this study, we explore the application of metaheuristics in creating circularity. We contend that these algorithms can catalyze the quest for efficient and effective circular or closed-loop systems (Seydanlou et al., 2023). Before delving deeper into the role of metaheuristics in delivering circularity, let us explore the nuances of these optimization techniques. Metaheuristics are optimization methods that leverage stochastic, iterative, and randomized algorithms (Fathollahi-Fard et al., 2023b). Unlike conventional optimization approaches, metaheuristics do not guarantee optimal solutions. Instead, they strive to identify high-

[1] https://www.statista.com/statistics/239662/size-of-the-global-recycling-market/ (Accessed on 14/08/2023).

quality solutions close to the optimal solution within a reasonable time frame (Ezugwu et al., 2021). Some noteworthy examples of metaheuristics are genetic algorithms (Vahdani and Ahmadzadeh, 2021) and particle swarm optimization (Parsopoulos et al., 2015).

Metaheuristics offer several potential applications in the pursuit of circularity. One promising avenue is their use in optimizing closed-loop supply chain design that aims to reuse, recuperate, and recycle resources and products (Porkar et al., 2020). Additionally, metaheuristics can facilitate the efficient allocation of resources in circular systems, such as renewable energy sources, waste treatment facilities, and transportation networks (Mosallanezhad et al., 2021; Shi et al., 2020). Furthermore, metaheuristics can contribute to the optimization of the scheduling and routing of circular processes, such as the collection and sorting of recyclable materials (Kuvvetli and Erol, 2020). To demonstrate the power of metaheuristics for enabling circularity, let us delve into some exemplary instances from the literature. For example, (Roghanian and Cheraghalipour, 2019) utilized five different metaheuristics to optimize a closed-loop citrus supply chain considering environmental impacts. The results of employing this approach demonstrated that the utilization of multiple transportation vehicles could effectively decrease CO_2 emissions while enhancing the values of all objective functions, particularly in terms of demand responsiveness. The study further indicated that by incorporating two novel assumptions into the model, namely, CO_2 emissions and the utilization of multiple vehicles, it is possible to achieve enhanced demand responsiveness and substantial reductions in emissions.

In their research, Eskandarpour et al. (2014) devised a mixed integer linear programming (MILP) mathematical model to optimize the selection of collection and recycling centers in reverse and forward logistics for returned and recovered products. The objective was to minimize the overall cost of the system. To tackle this optimization problem, the study introduced a novel heuristic method based on tabu search (TS). The TS-based approach proved more efficient and effective than the simulated annealing-based (SA) method, exhibiting a remarkable improvement in robustness by 2.18%. These examples showcase the immense potential of metaheuristics in optimizing circular systems for improved efficiency and sustainability (Moosavi et al., 2021).

Metaheuristics have a significant edge in facilitating circularity in the supply chain, and their strength lies in their capacity to handle intricate and constantly evolving systems. Circular systems (Moosavi et al., 2022) are typically known for their nonlinear and stochastic behavior, making it challenging to model and optimize them using traditional approaches (Habibi et al., 2019). Metaheuristics, however, have the ability to adapt to these changing conditions and explore a broad spectrum of solutions, making them a natural fit for modeling circular supply chain intelligent systems (Liu et al., 2021). Moreover, metaheuristics can aid in identifying the best trade-offs between conflicting objectives. For instance, balancing cost, environmental impact, and social equity is crucial in designing sustainable circular systems, and metaheuristics can help achieve this goal (Pop et al., 2015). In recent decades, meta-heuristics have gained increasing attention as a powerful and efficient method for addressing complex computational challenges and real-world problems in forward supply chain management (SCM) and reverse logistics (Lin et al., 2018). Table 1 provides an overview of previous literature review studies that examine the use of metaheuristics in logistics and SCM contexts. It also reflects how the focus of this study varies from earlier studies.

Table 1: Past literature review studies on metaheuristics

Author(s)	Focus of study	Number of articles	Keywords
(Ansari and Daxini, 2022)	Review of articles concerned with metaheuristics for remanufacturing applications	123	Supply Chain, metaheuristics, remanufacturing, and optimization, review
(Van Engeland et al., 2020)	Reviews literature on optimization models for reverse waste management supply chain	207	Reverse logistics, waste management, strategic network design, and supply chain management.
(Rachih et al., 2019)	Review of literature on metaheuristics in reverse logistics context.	120	Optimization, metaheuristics, and reverse logistics
(Ren et al., 2019)	A bibliometric review of studies concerned with green and sustainable logistics	306	Sustainable logistics, green initiative, freight transportation, bibliometric review
Our Study	A systematic review of metaheuristics literature in Circular intelligent system	77	Metaheuristics, closed-loop supply chain, circularity, reverse logistics, and systematic literature review

Despite some literature reviews and surveys highlighting the use of metaheuristics in forward SCM, few studies have explicitly and comprehensively examined the application of metaheuristic algorithms in the context of circular or reverse systems (Faramarzi-Oghani et al., 2023). We believe that applying metaheuristics for delivering circularity could be a promising area for future research and innovation. In this study, we attempt to investigate the current literature on metaheuristics applied in circular supply chain management based on the following research questions (RQs):

RQ1. With respect to optimization in the supply chain, what are the most pressing issues that meta-heuristics attempt to solve?

RQ2. Which optimization meta-heuristics are used to solve closed-loop or circular supply chain issues?

RQ3. Which characteristics of circularity do meta-heuristics incorporate?

We attempt to answer these research questions by developing a conceptual framework through a literature review. It encompasses supply chain challenges approached through metaheuristics, the classification of various types of metaheuristics, and the circularity outcomes of applying these metaheuristics in supply chain scenarios. The remaining portion of this article follows a well-structured format with multiple sections dedicated to a specific aspect. Section 2 outlines the research methodology for collecting and refining relevant materials employed in this study, elucidating the systematic approach adopted. Section 3 presents a descriptive analysis to offer preliminary insights into the current state of the literature under examination. Section 4 introduces a classification of metaheuristics and their characteristics. Building upon this, Section

5 delves deeper into the content analysis outcomes, presenting the significant findings from influential scholarly articles and illuminating potential avenues for future exploration. Section 6 encompasses an extensive discussion wherein a conceptual framework is established. Finally, Section 7 serves as a concluding segment, effectively summarizing the review's key outcomes, implications, and limitations.

2. Review methodology

As a crucial component of scholarly investigations, the literature review plays a pivotal role in establishing research by leveraging the existing wealth of knowledge within the field (Webster and Watson, 2002). This critical examination offers an all-inclusive perspective of the predominant body of literature in a specific domain, encompassing the meticulous gathering and synthesis of prior pertinent studies. Its primary objective is to augment scholarly discourse by reporting the discovered insights, highlighting the gaps in existing research, and proposing promising avenues for future exploration (Wee and Banister, 2016). This study thoroughly explores the literature on metaheuristics in circular systems to establish a strong analytical foundation for addressing the previously introduced research questions. We address these questions by utilizing a blend of descriptive and content analyses of past literature. Additionally, we identify cluster-based future research opportunities. Numerous researchers have successfully employed this systematic literature review approach (Goyal and Kumar, 2021; Samadhiya et al., 2023). Figure 1 displays the methodological approach utilized to conduct this literature review. Our study has been bifurcated into five distinctive phases: gathering research articles, screening articles, conducting a descriptive analysis, conducting a content analysis, and discussion.

- Phase 1: To begin the literature review, we embarked on the quest to gather research material related to metaheuristics and its implications on CLSC and reverse logistics. To pursue this objective, we thoroughly searched two databases, 'Scopus' and 'Web of Science.' Our search strategy involved using a carefully crafted search string containing relevant keywords such as 'Metaheuristics,' 'Circular,' 'Supply Chain,' 'Closed-loop supply chain,' and 'Reverse logistics.' The same search string was employed for both databases, leading to the discovery of 171 and 204 articles on 'Scopus' and 'Web of Science', respectively. After eliminating duplicates, we curated a consolidated sheet comprising 230 articles deemed suitable for the next phase of the review.

  Phase 2: The subsequent step in the literature review process was to screen the 230 documents obtained from the Scopus and Web of Science databases. We followed a strict protocol with three exclusion criteria to narrow the list. Initially, we removed papers classified as 'Review Papers' as they were irrelevant to our research focus. Furthermore, we eliminated articles that pertained to subjects outside our research domain, such as Applied Physics, Chemistry, and Public Health. Finally, we conducted a detailed screening of the abstracts and excluded 153 documents that did not qualify for the scope of the study, leaving us with 77 articles for the next phase.

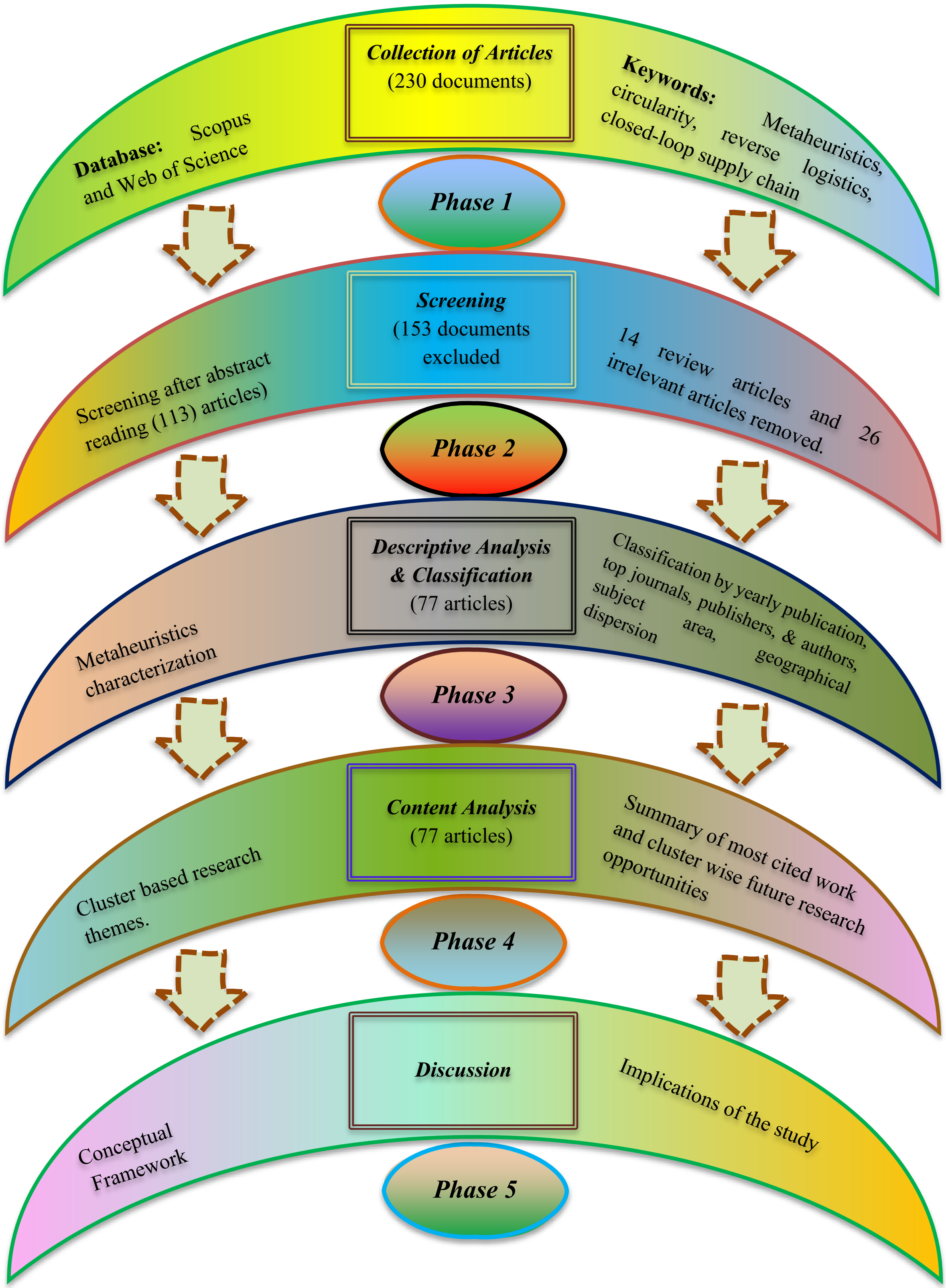

Figure 1: Review methodology

- Phase 3: Upon successfully completing the screening phase, we were left with a refined list of 77 articles. We employed R Studio Statistical software to conduct a thorough descriptive analysis. We classified the literature into six categories: articles published per year, top journals, major publishers by percentage share, prominent authors in the field, subject area distribution of articles, and the geographical spread of research in this domain. After conducting this investigation, we classify and characterize metaheuristics in the context of circularity.
- Phase 4: We conducted an exhaustive content analysis of the 77 research articles during this phase. We meticulously examined the research material to identify and categorize significant themes and then classified the material into four distinct clusters. We thoroughly reviewed and summarized the most popular articles under each cluster and proposed future research directions.
- Phase 5: The final stage of this systematic review involves putting forward a theoretical framework grounded in the outcomes of the descriptive and cluster-oriented content analysis of scrutinized articles. Our intention for this phase is to conclude the review procedure by examining the research implications.

3. Descriptive Analysis of Literature

Descriptive analysis of literature means carefully summarizing and showing the main traits, themes, and patterns discovered within a group of written works. Its emphasis lies in offering a snapshot of the content, concepts, and ideas conveyed in the literature without obligatory exploration into more profound interpretations or assessments (Tian et al., 2023). In this section, we have performed the descriptive analysis of the screened literature, utilizing the findings obtained from the R statistical software. The ensuing subsections of this section categorize the articles based on yearly publication, the leading publishers by percentage share, prominent authors, classification of articles according to subject areas, and the geographical distribution of articles based on country.

3.1 Yearwise publications

We thoroughly analyzed the publication dates of 77 selected research articles. Figure 2 presents the yearly distribution of these articles that examine the implementation of metaheuristics in circular systems. According to the graph, the use of metaheuristics to address issues within closed-loop supply chains began in the early 2000s, but the field has experienced remarkable expansion since 2014. An astounding 60% of all research papers in this field were published between 2018 and 2022. This explosive growth demonstrates the growing interest in and adoption of metaheuristics among scholars and industry professionals.

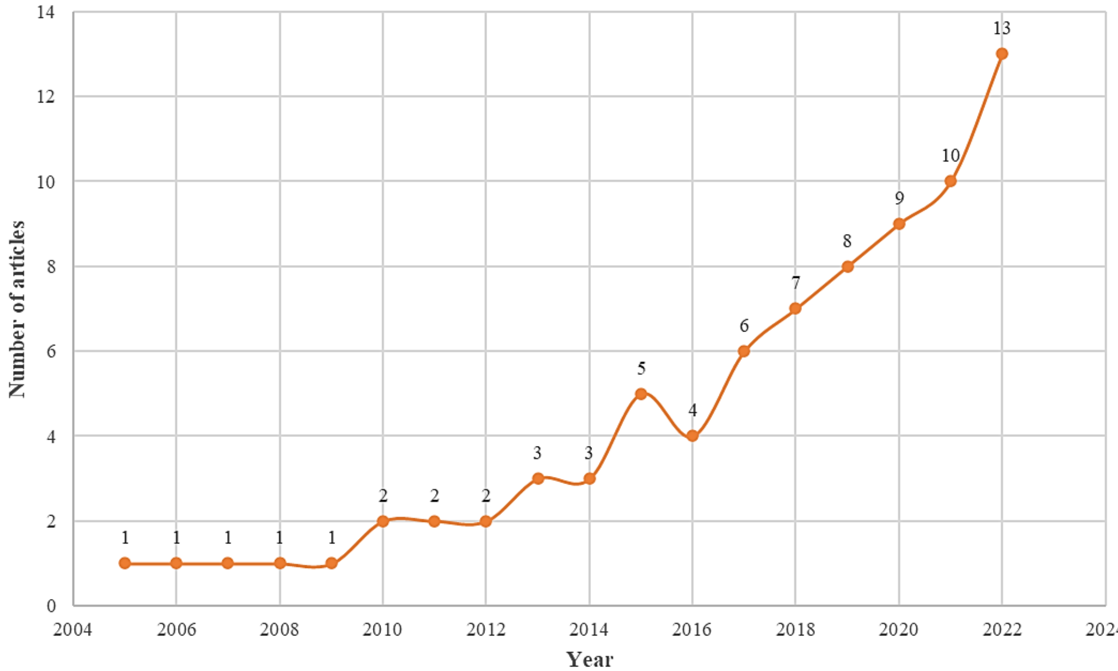

Figure 2: Annual publication trend

3.2 Top Journals

In the initial search results, we identified 230 documents that were published in a total of 87 journals. Figure 3 presents the leading journals promoting metaheuristics research for circularity and reverse logistics. The top 5 journals contributed to 47 documents in this field. The top-ranked journal was Computers and Industrial Engineering, with 11 research articles, followed by the "International Journal of Production Research" (10 articles), "Journal of Cleaner Production" (9 articles), "European Journal of Operational Research" (9 articles), and "International Journal of Production Economics" (8 articles).

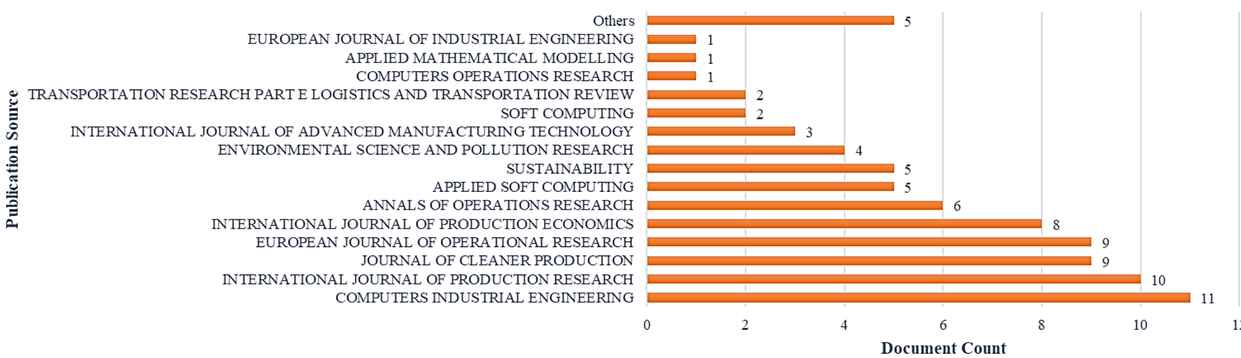

Figure 3: Most prominent journals

These journals are highly regarded in business and management domain research, receiving A and A* ratings according to the Australian Business Dean Council (ABDC) reports. For instance, "Computers & Industrial Engineering," "International Journal of Production Research," "Journal of Cleaner Production," "International Journal of Production Economics," and "Annals of Operations Research" are classified as A-category journals in ABDC reports. In contrast, the "European Journal of Operational Research" and "Transportation Research Part E: Logistics and Transportation Review" are ranked as A* category journals.

3.3 Major publishers by percentage share

The publishers who have played a significant role in disseminating research related to metaheuristics in closed-loop supply chain setups are presented in Figure 4. Among the list of major publishing houses, Elsevier stands out as the leading publisher, having published nearly half of all the research articles in this field. Other prominent publishers include Springer Nature (with a 20% share), Taylor and Francis (with a 12% share), MDPI (with a 7% share), INFORMS (with a 2% share), and Wiley (with a 2% share).

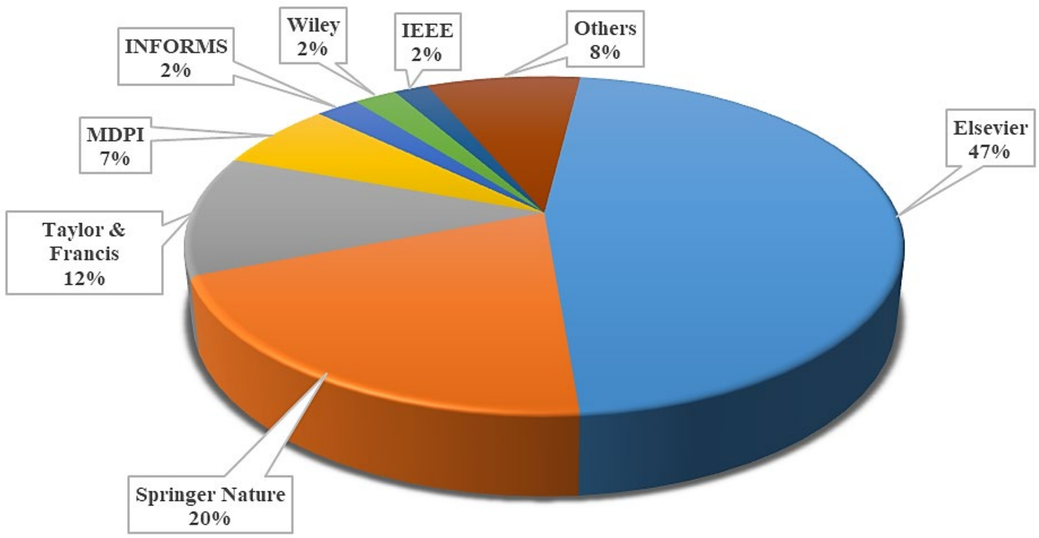

Figure 4: Top publishers

3.4 Leading authors

A total of 230 articles initially received from 343 organizations were written by 829 authors. Figure 5 portrays the prominent contributors to metaheuristics research in the context of closed-loop systems for circularity and reverse logistics. The figure highlights Hajiaghaei-Keshteli M as the leading author, with 14 articles related to metaheuristic applications during the considered period. Fathollahi-Fard AM comes next with eight published articles, followed by Guo H with seven pieces, Tavakkoli-Moghaddam R and Zhang Y with six articles each, and Soleimani H with five. Other notable authors have also contributed significantly to the field.

3.5 Subject areawise classification

The findings of this study display the distribution of published articles in various subject areas that focused on the application of metaheuristics in the context of circularity and reverse logistics within CLSC. Figure 6, presented as a funnel diagram, visually represents this distribution. "Operations Research Management Science," "Engineering," "Computer Science," and "Environment Science and Ecology" contribute to approximately 68% of the published articles.

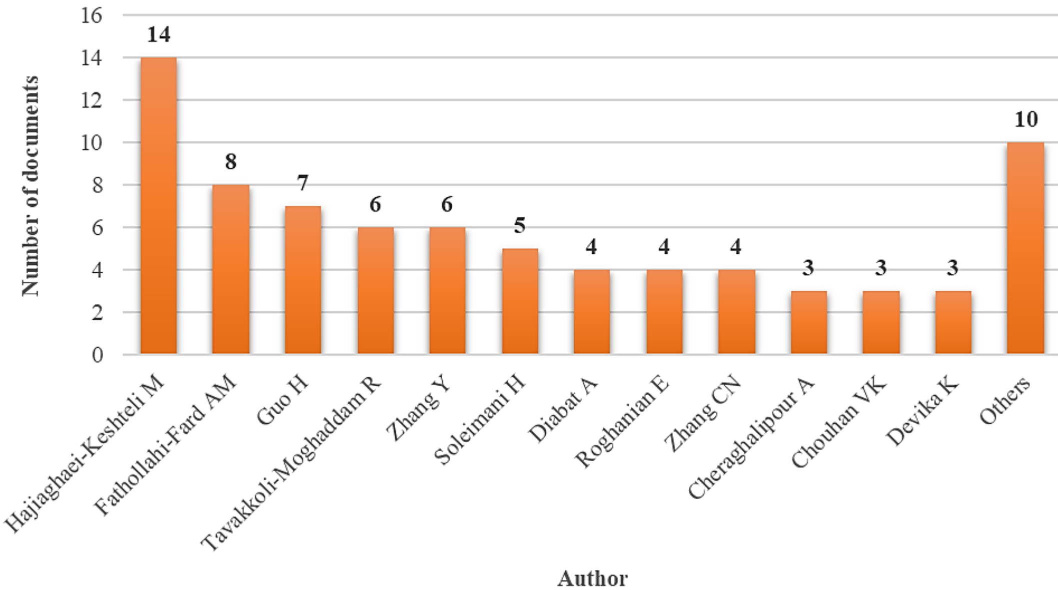

Figure 5: Leading authors

In addition, metaheuristic applications were also found in other subject areas, such as science and technology, business economics, mathematics, automation control systems, and transportation. The high contribution in "operations research management science," "engineering," and "computer science" is likely due to the prevalent use of pure and hybrid optimization metaheuristics to achieve business objectives. The significant share of environmental science and ecology highlights the importance of metaheuristics in achieving circularity and reverse logistics planning in closed-loop supply chain systems.

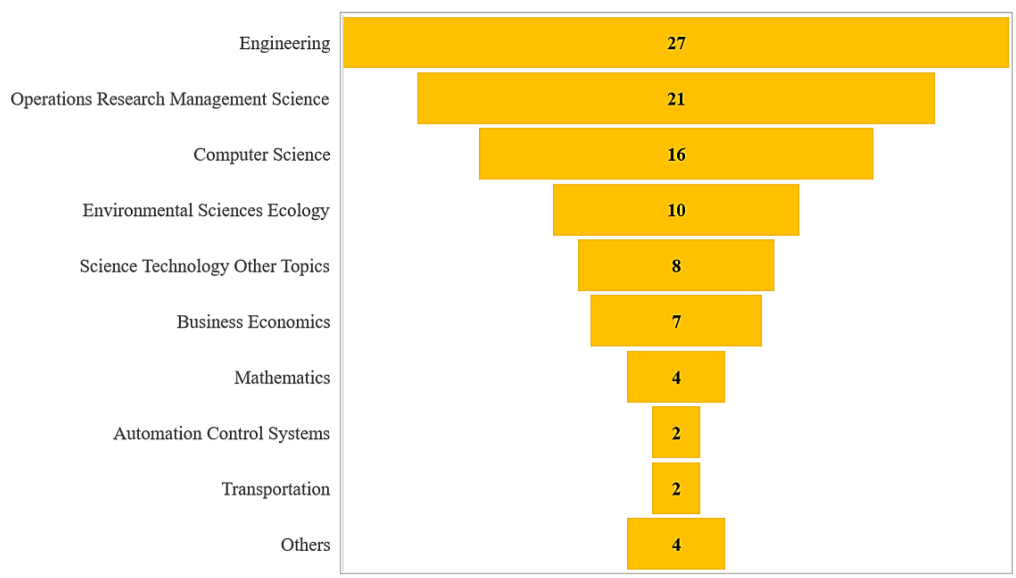

Figure 6: Subject areawise distribution

3.6 Geographical Distribution of Articles

The distribution of articles by country provides a glimpse of the global collaboration among researchers and practitioners involved in metaheuristics research for circularity. As shown in Table 2, a diverse range of countries contributed to the study, with Iran taking the lead by publishing the maximum number of articles (19), followed by China (13 articles) and the USA (11 articles). Other countries that have made significant contributions to the research include France (7 papers), Canada (5 articles), the United Kingdom (5 articles), Germany (3 articles), and India (3 documents), among others.

Table 2: Countrywise publications

Countries	Frequency of published articles
Iran	19
China	13
USA	11
France	7
United Kingdom	5
Canada	5
India	3
Germany	3
Turkey	2
Australia	1
Others	8

To provide a visual representation of the geographical distribution of metaheuristic research initiatives, a world map was used, as shown in Figure 7. The countries are represented by different colors based on the frequency of published articles. Light orange represents a low frequency, slightly darker orange indicates a medium frequency, and dark red shows a high frequency of published research in the region. It is evident from the map that the South American and African continents are not well represented in the metaheuristics-related study, while countries such as Iran, China, and the USA are at the forefront of research in this domain.

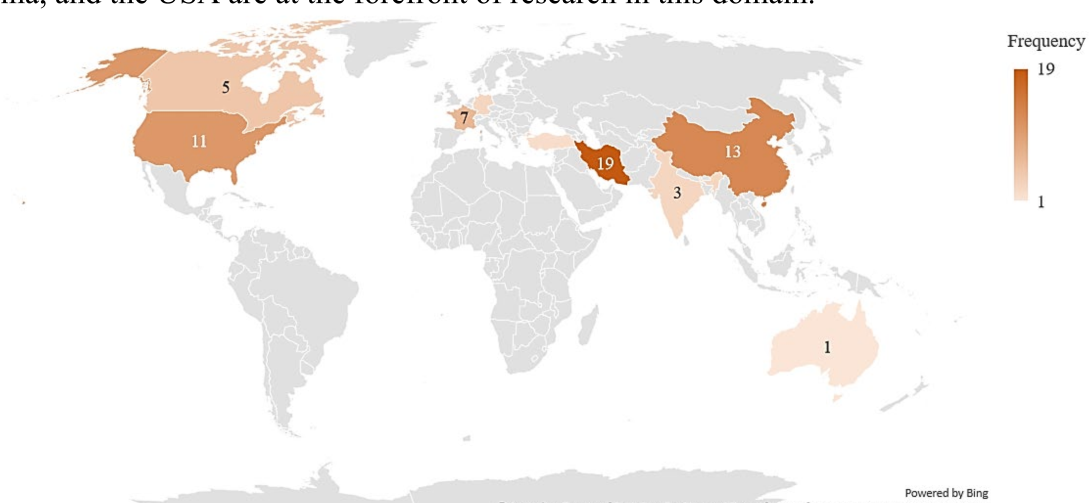

Figure 7: Geographical distribution of articles

4. Metaheuristics characterization: a classification in the circularity context

This section aims to categorize metaheuristics and explore their potential contributions to achieving circularity in supply chain optimization problems. Figure 8 illustrates a comprehensive classification of metaheuristics, distinguishing between pure and hybrid approaches. Under the category of pure metaheuristics, we have the "Genetic Algorithm (GA)," "Variable Neighborhood Search (VNS)," "Simulated Annealing (SA)," "Particle Swarm Optimization (PSO)," "Tabu Search (TS)," and "Keshtel Algorithm (KA)". In contrast, hybrid metaheuristics encompass algorithms such as the Imperialist Competitive Algorithm (ICA), algorithms based on GA & SA (GASA), algorithms based on KA & SA (KASA), and algorithms based on KA & GA (KAGA).

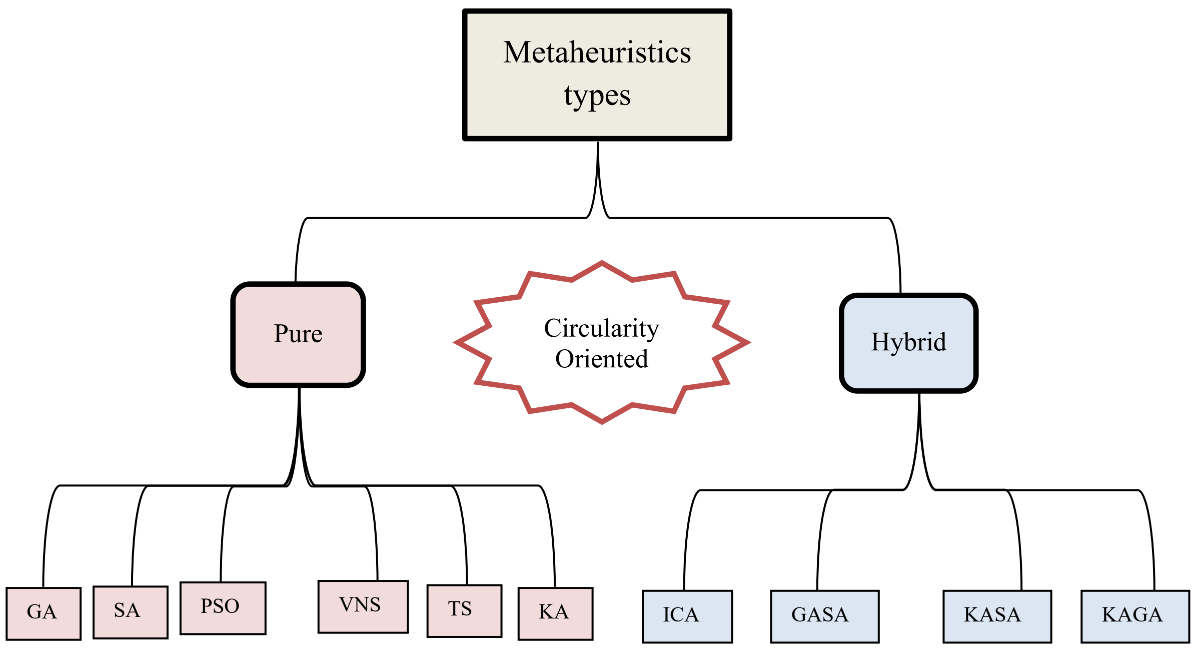

Figure 8: Broad classification of metaheuristics

We have conducted a comparative analysis of several widely used metaheuristics to examine the strengths and constraints of metaheuristics. Table 3, presented below, provides a succinct overview of the reviewed metaheuristics, highlighting their application in the context of circularity and the advantages and limitations associated with their implementation. In the subsequent section, we will delve deeper into content analysis, exploring the diverse applications of these metaheuristics in addressing a wide range of supply chain complexities. Through this analysis, we will gain further insights into how different studies have harnessed the power of these metaheuristics to effectively tackle various challenges in the supply chain domain while also embracing circularity principles in their operations.

Table 3: Characteristics of metaheuristics

Reference	Algorithm	Advantage of algorithm	Limitation of algorithm	Application in circularity context

(Antuchevicicne et al., 2020; Chern et al., 2014; Zhang et al., 2021)	Genetic Algorithm (GA)	Convenient to implement and can handle random constraints and objective functions	No standard fitting function is defined, and there's uncertainty over it producing a global optimal solution	• Vehicle routing in e-commerce reverse logistics • planning product structures using substitutions, recycled components, and common components. • Minimizing adverse environmental impacts in reverse logistics
(Vali-Siar et al., 2022)	Particle Swarm Optimization (PSO)	Handy in scientific research and easier calculations are involved	Solution conversion happens quickly without considering the diversity of the population	Managing disruptions and operational risks in closed-loop supply chain
(Bagheri Hosseini et al., 2019)	Variable neighborhood search (VNS)	It searches for optimal solutions during both the perturbation and descent phases.	Parameter selection hugely affects the computational results	Collection of returned products
(Taheri and Moghaddam, 2022)	Simulated Annealing (SA)	Easy to implement, robust in nature, works well with nonlinear and noisy data	High parameter tuning is required	Sustainable supply chain design in healthcare systems
(Kalayci et al., 2016)	Tabu Search (TS)	An adaptive memory-based technique capable of providing flexible search solutions	It might get stuck on a feasible solution, leaving out other neighborhood solutions.	Balancing of disassembly line in product recovery operations
(Vahdani and Ahmadzadeh, 2019)	Imperialist Competitive Algorithm (ICA)	High convergence rate due to applicability for both continuous and discrete search spaces	The quality of solutions is highly affected by parameter tuning	Inventory management and facility location in closed-loop supply chain
(Chouhan et al., 2020)	Keshtel Algorithm (KA)	Less likely to stop at local optimal solutions	High computational time	Collection of end-of-use and end-of-life products from customer

5. Content Analysis

Within the context of a systematic literature review, content analysis entails a methodical appraisal and examination of the substance found within chosen research articles or other pertinent sources. This rigorous process thoroughly scrutinizes the accumulated data to uncover discernible patterns, prevalent themes, and noteworthy information aligning with the research objectives or questions (Kazemi et al., 2019). As part of our investigation, we identified four distinct clusters within the corpus of research materials under scrutiny. To illuminate the paramount contributions within each cluster while avoiding repetitive themes, we focus our discussion on articles that best encapsulate the cluster's essence and have garnered at least twenty citations or more. The content analysis section will comprehensively understand the insights gleaned from each cluster's most widely recognized articles. We will also present potential avenues for future research pertaining to each cluster.

5.1 Cluster 1: Type of supply chain

Within this captivating cluster, a meticulous analysis is conducted, offering a fresh perspective on the realm of supply chains. A total of 15 articles were classified under this cluster. Here, we explore two distinct paradigms that have captured the attention of researchers. The first lens through which we examine these articles unveils a keen focus on the intricacies of reverse logistics, i.e., where the focus is on how a product is sent back to the supply chain for recycling, reprocessing, or remanufacturing. The second supply chain archetype that commands our attention is the closed-loop supply chain, a dynamic system that seamlessly intertwines the forward and reverse flows of products and materials.

i. Closed-loop supply chain (CLSC)

In a study (Sahebjamnia et al., 2018) cited 163 times, a visionary research team unveiled a cutting-edge model that revolutionizes the design of a tire closed-loop supply chain network, aligning economic objectives with environmental and social considerations. This model goes beyond conventional approaches, as it seeks to optimize the total cost of operations and the environmental effect stemming from facility establishment, tire processing, and transportation across each level. Moreover, it considers the profound social impact, including job opportunities and work damage. Fueling the innovation further, the authors devised four ingenious hybrid metaheuristics tailored to solve complex networks on a grand scale efficiently. These algorithms were subjected to rigorous evaluation involving extensive computational experiments, meticulous comparisons, and intricate sensitivity analyses, ensuring their robustness and effectiveness in transforming the landscape of tire closed-loop supply chains.

With 84 impressive citations, Vahdani and Mohammadi (2015) introduced a binary-objective optimization model that enables network design in a closed-loop supply chain (CLSC) considering uncertainty. The model encompasses the maximum waiting times in the product queues and the total costs as objectives to minimize. Pioneering the way forward, the visionary authors unveiled a usual multiple-priority and multiple-server queuing scheme, enabling seamless execution of parallel processing. In this article, the authors developed a novel hybrid solution approach based on interval programming, stochastic programming, fuzzy multiobjective programming, and a robust optimization approach. Further authors also put forth a meta-heuristic algorithm in the study.

With a remarkable citation count of 63, Yavari and Geraeli (2019) present an all-encompassing blueprint for a CLSC network design catering to the requirement of perishable products. This ground-breaking article prioritizes the eco-conscious objective while optimizing costs by meticulously scrutinizing the lifecycle-induced ecological ramifications stemming from the various facets of the supply chain's operations, including the construction of facilities, transportation, and inventory management. In a stroke of ingenuity, the authors harnessed the power of mixed-integer linear programming (MILP) to devise a sophisticated model that concurrently minimizes both costs and the detrimental impact of environmental pollutants. Furthermore, the article proposes an ingenious and highly efficient heuristic named YAG, offering a potent solution for tackling the complex challenges posed by large-scale problems. Throughout their rigorous investigation, the authors thoroughly examine factors such as the product's lifespan, the intricacies of biobjective modeling, and the pervasive influence of environmental contaminants.

ii. Reverse Logistics

In recent years, reverse logistics has gained significant recognition as an indispensable component of supply chain operations among advanced economies. This heightened recognition stems from the realization that returned or deemed obsolete materials still possess inherent value and can be reintegrated into the supply chain with minimal modifications (Berlin et al., 2022). Within the realm of reverse supply chains, disassembly serves as a systematic approach for deconstructing assemblies into their constituent components, subassemblies, or other relevant groupings, thereby facilitating the discerning extraction of necessary parts and constituents from returned goods. Disassembly lines, renowned for their exceptional efficiency and adaptability to automation, represent the best configuration for facilitating product recovery operations.

In their ground-breaking research that garnered an impressive 136 citations, Kalayci et al. (2016) delved into the intricacies of the "Sequence-dependent disassembly line balancing problem" (SDDLBP). This complex conundrum involves allocating disassembly operations to a series of meticulously numbered workstations while diligently adhering to optimizing multiple objectives and disassembly precedence constraints that encompass a range of time-based factors influenced by the sequence-dependent nature of the process. To tackle this challenge head-on, the authors devised a revolutionary hybrid algorithm that ingeniously combines the power of a genetic algorithm with the versatility of a "variable neighborhood search" method, aptly named VNSGA. The authors conducted a comprehensive performance analysis through extensive experimentation, pitting VNSGA against the most prominent metaheuristics documented in the prevalent literature. The results undeniably showcased the unmatched dominance of the proposed methodology, firmly establishing it as the benchmark for achieving optimal solutions within the realm of SDDLBP research. In the case supply chain of citrus fruits, the ruined fruits at each stage of the value chain are one of the key challenges for stakeholders in both the public and private sectors.

The study by Cheraghalipour et al. (2018), which has received 76 citations, developed a novel mathematical model specifically for optimizing the dynamics of a citrus fruit supply chain industry. The authors introduced a "multiobjective Keshtel algorithm" (MOKA) as an innovative solution approach for the proposed model to tackle the challenge. To gauge the superiority and effectiveness of their proposed MOKA, a comprehensive comparative analysis was conducted against several well-established algorithms, including the "nondominated ranking genetic algorithm" (NRGA), "multinon-dominated sorting genetic algorithm" (NSGA-II), and "multiobjective simulated annealing" (MOSA). The authors have shed light on the MOKA algorithm's distinctive advantages and performance characteristics through this rigorous evaluation. A compelling citrus closed-loop supply chain case study was presented to further demonstrate the practical relevance and applicability of the proposed model and solution method, underscoring the real-world pertinency and tangible benefits of implementing this innovative approach.

In the realm of designing reverse logistics networks, a multiobjective optimization model was proposed by Tuzkaya et al. (2011). This study has garnered substantial recognition with 41 citations, highlighting its significance within the field. The authors introduced an innovative approach consisting of two distinct stages: the "centralized return center" (CRC) evaluation stage and the "reverse logistics network design" (RLND) phase. To effectively evaluate the CRC, the authors employed an integrated methodology that combined the "analytic network process" (ANP) with the "fuzzy technique for order of preference by similarity to the ideal solution" (fuzzy-TOPSIS). This comprehensive evaluation framework facilitated a robust assessment of the CRC's efficiency and effectiveness. Additionally, the authors applied the proposed procedure to a compelling case study from the Turkish industry for white goods, allowing for a detailed examination of its practical applicability and real-world implications. Table 4 below lists the potential research questions identified under this cluster.

Table 4: Future research opportunities identified under Cluster 1

Identified research gap	Future research opportunities
1. The effect of government interventions needs to be studied in the design of closed-loop supply chain networks for sustainable tires.	• What is the impact of government policies and regulations on the design of closed-loop supply chain networks for sustainable tires?
2. The existing algorithms and optimization models do not consider the impact of consumer behavior and preferences on the design of sustainable tire closed-loop supply chain networks.	• How do customer preferences and behavior affect the closed-loop supply chain network design for sustainable tires?
3. There is a need to develop a model that can handle more complex disassembly line balancing problems.	• How do uncertain demand or stochastic processing times products impact the performance of sequence-dependent disassembly lines?
4. While designing a "closed-loop supply chain" (CLSC) network in which overall costs and the maximum waiting times in the queue of products are studied, there is a need to incorporate multiple uncertainties.	• What is the impact of multiple periods on a closed-loop supply chain network which attempts to minimize the total cost and maximum waiting time?

5. There is a need to evaluate the impact of different factors, such as cost and fruit quality, in the optimization model concerned with the network design in the closed-loop supply chain of citrus fruits.	• What is the impact of different factors, such as quality of returned products, inventory holding costs, and transportation costs, on the performance of the citrus closed-loop supply chain?
6. The effect of multiple uncertainties should be studied in a closed-loop network design for perishable products.	• How do capacity, lead time, and quality of products affect the supply chain network design for perishable items?
7. There is a need to incorporate multiple objectives in the network design problem for perishable products.	• How can environmental pollutants, costs, and other objectives, such as customer happiness and social responsibility, be considered in a multiobjective optimization model for network design of the perishable product supply chain?
8. An investigation should be carried out to maximize resource utilization in reverse logistics network design.	• How to integrate resource utilization such as transportation, labor, and facility while designing the network for reverse logistics?
9. There is a need to introduce more managerial objectives in the reverse logistics network design optimization models.	• How do operational and tactical level objectives related to production planning and inventory management affect the performance of reverse logistics network design?

5.2 Cluster 2: Optimization problem addressed

Within this particular cluster, a collection of articles has garnered substantial citation counts, showcasing their focus on employing mathematical modeling and metaheuristics to resolve conventional optimization problems within the supply chain domain. A total of nineteen articles have been classified under this category, highlighting a wide array of optimization challenges prevalent in the circularity context of supply chains. The investigation conducted by Zhalechian et al. (2016), which holds the highest number of citations (231) within this cluster, formulated an innovative and sustainable closed-loop location-inventory routing planning (LIRP) framework amidst a combination of uncertainties. The authors considered the financial, ecological, and societal ramifications encompassing CO_2 emissions, fuel usage, energy wastage, employment opportunities, and economic growth. To tackle the unpredictable characteristics of the network, the research employed a stochastic-possibilistic programming methodology. The authors also introduced a mixed-integer, multiobjective, nonlinear mathematical programming model to minimize overall investments, transportation, inventory, and environmental expenditures while maximizing the positive social effects of supply chain network design. Moreover, the authors devised a hybrid meta-heuristic algorithm and established lower boundaries for solving substantial-scale predicaments.

In their research, Schultmann et al. (2006), which garnered 193 citations, delved into the intricacies of facilitating a closed-loop supply chain (CLSC) by taking the example of end-of-life vehicle (ELV) treatment in Germany. The authors also put forth various alternatives for CLSC design, emphasizing managing the reverse material flow and their reintegration into their original supply chains seamlessly. Additionally, the study incorporated reverse logistics elements alongside vehicle routing planning (VRP). To analyze multiple CLSC scenarios using authentic data from German ELV stakeholders, the authors introduced a customized algorithm tailored to address the problem at hand. Moreover, the authors extensively discussed the outcomes of the CLSC scenarios and outlined measures that can be implemented to enhance the ELV treatment process in Germany. Examining the network design quandary of a CLSC that merges the acquisition of preowned items with the dissemination of novel products, Kaya and Urek (2016) garnered a notable 96 citations. The authors of this study presented a comprehensive mixed-integer nonlinear model termed facility "location-inventory-pricing (LIP)" to determine the most favorable facility placements, inventory quantities, pricing schemes for new items, and incentivizing factors for the collection of an optimal volume of used products, thereby maximizing the overall profitability of the supply chain. Furthermore, the investigation devised efficient heuristic techniques to tackle and resolve this intricate model.

Introducing a ground-breaking contribution, Fathollahi-Fard et al. (2018a), acclaimed with 59 citations, presents an innovative tri-level programming model for the inaugural design of the location-allocation problem (LAP) within the tire closed-loop supply chain (CLSC). By formulating the model based on a static Stackelberg game involving distributors, collectors, and manufacturers within the CLSC framework, the study pioneers a fresh approach to tackle this domain. Additionally, the paper introduces a series of novel hybrid optimizers that incorporate the advantages of recent metaheuristic techniques specifically tailored to address extensive-scale predicaments. Demonstrating remarkable efficiency, both the proposed model and hybrid optimizers showed their efficacy in effectively resolving the CLSC location-allocation problem (LAP). Presenting an innovative perspective, Pishvaee and Rabbani (2011), acknowledged with 33 citations, introduces a pair of mixed-integer programming models targeting the multistage, adaptable "supply chain network design" (SCND) predicament. These models address two distinct scenarios: one allowing direct shipments and the other prohibiting them. Leveraging the power of graph theory, the authors examine the structural aspects of the SCND quandaries and establish that a bipartite graph can effectively represent both situations. Furthermore, the research pioneers a ground-breaking heuristic approach by leveraging a novel representation method derived from graph theory, offering a viable path to resolve the intricate problem. This study successfully delivers an efficient solution method catering to the demands of multistage, single-product, and responsive supply chain network design issues, taking into account both direct and indirect shipments. Habibi et al. (2017) emerges with 23 citations and offers a remedy for the collection-disassembly problem experienced within a reverse material flow phase in a closed-loop supply chain. To tackle this complex challenge, which falls under the domain of production routing problems (PRPs), the authors present a remarkable two-phase iterative heuristic specifically designed to tackle sizable instances of the problem. Through comprehensive numerical evaluations, the authors demonstrate the efficiency of the heuristic by showcasing its ability to generate commendable solutions within reasonable computational timeframes. The recommended research questions discovered within this cluster are shown in Table 5.

Table 5: Future research opportunities identified under cluster 2

Identifies research gap	Future research opportunities
1. Several related challenges should be incorporated while developing a "closed-loop location-inventory routing problem" based model.	• How do facility disruption and pricing decisions impact the design of a sustainable closed-loop location-inventory routing (LIRP) model?
2. Some environmental considerations are missing in the existing closed-loop location-inventory routing problem-based models.	• How can environmental factors such as water pollution, noise pollution, and waste disposal be incorporated into sustainable closed-loop location-inventory routing (LIRP) network design?
3. There are few studies analyzing the potential of digital technologies to supplement the closed-loop supply chain design for end-of-life products.	• How do using digital technologies such as the Internet of Things (IoT) and blockchain affect the transparency and efficiency of CLSCs established for end-of-life vehicle (ELV) treatment?
4. Very few studies consider aspects other than reverse logistics while designing a closed-loop supply chain.	• How do product design and consumer behavior factors affect establishing closed-loop supply chains (CLSCs)?
5. Additional requirements should be incorporated in existing location-inventory-problems (LIP) models.	• How do capacity limits, multiproduct systems, quality differentiation for returns, uncertainty in demand, and return rate affect the performance of the facility location-inventory-pricing (LIP) model?
6. When designing a closed-loop supply chain location-allocation problem (LAP), certain uncertainties should be considered.	• How do uncertainties such as demand fluctuations, pricing changes, and transportation disruptions impact the CLSC model for location-allocation problems?
7. Graph theory has limited applications in supply chain network design (SCND).	• How can closed-loop or multiproduct supply chain network design problems be studied and analyzed using graph theory?
8. Collection-Disassembly Problem associated with the reverse material flow in the closed-loop supply chain should be modeled with additional constraints.	• What is the impact of the additional constraint of time windows and capacity constraints on the performance of the Collection-Disassembly model for reverse material flow in a "closed-loop supply chain"?

- How to extend the Collection-Disassembly model for reverse material flow in a closed-loop supply chain for multiple disassembly facilities?

5.3 Cluster 3: Type of metaheuristics employed

Within this cluster, we organized the scholarly works according to the metaheuristics employed by the authors within the examined research material. A total of 21 articles were assigned to this cluster classification. We further categorize these metaheuristics into two distinct subgroups, thus enhancing the granularity of our analysis.

i. Pure metaheuristics

Pure metaheuristics, often referred to as original algorithms, stand as independent methodologies untouched by hybridization or modification. These pure metaheuristics find application in both single-objective optimization and multiobjective optimization challenges. The genetic algorithm (GA), simulated annealing (SA), and variable neighborhood search (VNS) are some examples of pure metaheuristics. Further discussion in this section emphasizes the application of pure metaheuristics in various popularly cited studies. Fathollahi Fard and Hajaghaei-Keshteli (2018) emerged as noteworthy contributors with an impressive 76 citations and introduced a novel tri-level location allocation design quandary that concurrently accounts for both forward and reverse networks. The authors successfully framed the problem as a static Stackelberg game involving customer zones (CZs), distribution centers (DCs), and recovery centers (RCs), showcasing their astute problem formulation. Furthermore, the research unveiled a straightforward nested tri-level metaheuristic approach to tackle extensive-scale predicaments with remarkable efficiency. In this particular study, the authors harnessed the power of three time-honored methods, namely, “variable neighborhood search (VNS)”, “particle swarm optimization (PSO)” and “tabu search (TS)”, alongside two cutting-edge nature-inspired solution approaches known as “water wave optimization (WWO)” and “Keshtel algorithm (KA)”. These methodologies were meticulously compared to gauge their effectiveness in resolving the problem. Employing the Taguchi experimental method, the authors determined appropriate parameter values and validated the algorithms through a meticulous real-life case study. The comprehensive research demonstrated the prowess of tri-level metaheuristics as a viable approach for effectively addressing intricate tri-level models within large-scale networks. Presenting a ground-breaking contribution, Tirkolaee et al. (2022) garnered an impressive 77 citations by devising a mathematical framework for a sustainable closed-loop supply chain network (CLSCN) design specifically tailored to mask production and distribution during the unprecedented COVID-19 outbreak. This study holistically addressed locational determinations, supply chain logistics, production strategies, distribution channels, collection procedures, quarantine measures, recycling initiatives, reuse potential, and appropriate disposal methods within a multiechelon, multiproduct, and multiperiod supply chain environment. By prioritizing sustainable development, the authors aimed to concurrently minimize collective costs, environmental impact, and human risk. To tackle this multifaceted challenge, the authors employed the cutting-edge "Multi-Objective Gray Wolf Optimization" (MOGWO) metaheuristic approach and the well-regarded "Non-Dominated Sorting Genetic Algorithm II" (NSGA-II) to obtain Pareto optimal solutions for the proposed model. To assess the efficacy of their approach, the authors employed four assessment metrics, including "Spread of Non-Dominance Solution" (SNS), Max-Spread, "Mean Ideal Distance" (MID), and "Number of Pareto Solutions" (NPS). Furthermore, the authors conducted a real-world case study of Tehran, Iran, providing empirical evidence to substantiate the proposed mathematical model and assess its practical applicability.

ii. Hybrid metaheuristics

In the realm of academic exploration, the integration of diverse metaheuristics has gained momentum, leading to the emergence of hybrid metaheuristics, as evident in the literature review. The amalgamation of algorithms can be accomplished through various approaches, presenting exciting possibilities. These avenues include the fusion of two pure metaheuristics, hybridization involving one heuristic and one metaheuristic, or the combination of metaheuristics with mathematical techniques (Cruz-Duarte et al., 2021). The imperialist competitive algorithm (ICA), an algorithm obtained from hybridizing the Keshtel algorithm and genetic algorithm (KAGA), is an example of hybrid metaheuristics. Some of the most prominent papers are discussed further in terms of their usage of hybrid metaheuristics. Making a significant impact within this cluster, Devika et al. (2014) stands out impressively with a staggering 307 citations. The researchers embarked on an ambitious endeavor, crafting an innovative multiobjective, multiechelon model to design a comprehensive logistics network. This encompassed suppliers, plants, distribution centers, retailers, customer zones, collection/inspection centers, and recycling facilities. Emphasizing the importance of sustainability, the authors deftly considered the three fundamental pillars—economic viability, environmental impact, and social welfare—while tackling the intricate network design problem. In a remarkable display of ingenuity, the study introduced three ground-breaking hybrid metaheuristic approaches that leveraged variable neighborhood search (VNS) and adapted imperialist competitive algorithms (ICA) techniques to address the NP-hard nature of the problem at hand. To validate the effectiveness and efficiency of these developed algorithms, the authors conducted comprehensive comparisons against other notable contenders. Furthermore, they illustrated their approach's practicality and real-world relevance by presenting a compelling case study within the glass industry. Fathollahi-Fard et al. (2018b) amassed an impressive 102 citations, which is a testament to its profound impact by ingeniously incorporating economic and social considerations in designing a closed-loop supply chain network. This notable study introduces a cutting-edge multiobjective stochastic programming model, harmonizing four inherently conflicting objectives within the realms of economic and social dimensions. In addition, the study brings forth innovative contributions, including the incorporation of downside risk valuation, the artful hybridization of algorithms, and the meticulous fine-tuning of recent

methodologies to effectively tackle the problem at hand. Remarkably, these endeavors culminate in the outperformance of existing techniques, as evidenced by comprehensive case studies. The study thus exemplifies a pioneering approach that transcends boundaries and maximizes the alignment of economic and social interests within the complex landscape of CLSC network design.
Hajiaghaei-Keshteli and Fathollahi Fard (2019) garnered an impressive 101 citations and delved into uncharted territory by devising a unique nonlinear programming mixed integer model specifically tailored to address the complex challenge of sustainable CLSC network design. A ground-breaking element introduced by the authors was the inclusion of a discount assumption within the transportation costs, a pioneering concept within the model. To tackle this multifaceted problem, the study harnessed a combination of traditional and state-of-the-art metaheuristics, strategically hybridizing them based on their strengths, particularly in terms of intensification and diversification capabilities. The authors conducted a comprehensive assessment, comparing the effectiveness and efficiency of these algorithms using four assessment metrics to analyze Pareto optimal solutions. Intriguingly, through the proposal of three new hybridization algorithms, the authors demonstrated that KAGA stands out by consistently delivering superior solutions, albeit with a trade-off of requiring additional computational time. Finally, the authors presented a compelling real-world case study within the glass industry, providing empirical evidence to validate the proposed model and algorithms in a practical industrial setting.

Chouhan et al. (2021) garnered 36 citations and embarked on a ground-breaking endeavor by designing an innovative and highly competent multiechelon Sugarcane Supply Chain Network (SSCN) capable of effectively managing the byproducts generated by the sugarcane business. Byproducts possess tremendous potential for further utilization with minimal modification. To address this complex challenge, the study introduced a robust "mixed-integer linear programming" (MILP) model, utilizing the concept of minimum opening cost to strategically position facilities and make informed decisions to minimize the overall supply chain cost. Moreover, the authors emphasized the importance of economically viable and environmentally friendly recycling methods for waste produced by refineries. To tackle the complexity inherent in the problem, the authors proposed three distinct hybrid metaheuristics: H-KASA (an amalgamation of Keshtel algorithm and simulated annealing), H-GASA (a fusion of simulated annealing and genetic algorithm), and H-RDASA (a combination of Simulated Annealing and Red Deer Algorithm). These novel hybrid algorithms effectively addressed the intricacies of the problem, surpassing the performance of their basic algorithm counterparts (GA, KA, RDA, and SA). To optimize these algorithms further, the authors employed Taguchi experiments to identify the optimal combinations of parameters. The study also compared comprehensively, evaluating the efficacy of the hybrid algorithms using various criteria. The authors generated a comprehensive group of test problems to ensure the model's versatility and applicability, verifying its robustness and effectiveness. Sensitivity analysis further confirmed that implementing the proposed multiechelon sustainable supply chain network would empower decision-makers to achieve a substantial 8.3% reduction in total cost, affirming its potential to drive significant cost savings. The proposed future research directions for this group are presented in Table 6.

Table 6: Future research opportunities identified under Cluster 3

Identified research gap	Future research opportunities
1. There is a need for modeling uncertainty related to time in a sustainable closed-loop, multiechelon, multiobjective logistics network design.	• What is the impact of a periodic timeline to analyze the time-related decisions, such as backlogging, forecasting, and ordering in the network design for a sustainable closed-loop, multiechelon, multiobjective logistics network?
2. The proposed model focuses on the economic dimension of CLSC can have more real-life logistics constraints.	• How do cross-docking operations affect the economic dimension in the network design for a closed-loop supply chain?
3. The hybridized metaheuristics employed for designing a sustainable CLSC network should be fed more diverse constraints and solved on a bigger scale.	• How do the logistic constraints related to vehicle routing practices and industry type affect the performance of mixed integer nonlinear programming models for network design problems in a sustainable CLSC?
4. Existing multilevel decision-making models for network design in reverse logistics can be extended to more constraints to reduce the transportation cost in the supply chain.	• For a multilevel decision-making model designed for a location-allocation design problem that considers only reverse networks, how do constraints of multicommodity, the uncertainty of parameters, and stochastic modeling affect the network decisions and transportation cost?
5. The existing models designed for location-allocation problems do not consider demand and supply side uncertainties.	• How does uncertainty in supply, demand, and transportation affect the performance of the supply chain network in forward and backward logistics in location-allocation problems?
6. Attempts should be made to incorporate the ever-changing demand in the Closed-Loop Supply Chain for sustainable medicinal items.	• How to incorporate simulation-based demand into the mathematical modeling to design a sustainable medical product based Closed-Loop Supply Chain Network (CLSCN) during a pandemic?
7. Uncertainty approaches should be included in the mathematical model developed for sustainable "Closed-Loop Supply Chain Network" (CLSCN) design of medical items.	• How do we incorporate approaches, such as robust optimization, fuzzy programming, stochastic optimal control, and gray systems, to deal with the uncertainty in the sustainable "Closed-

	Loop Supply Chain Network" (CLSCN) design of medical items?
8. The optimization models for multiechelon Sugarcane Supply Chain Networks (SSCN) to handle the byproducts yielded from the sugarcane industry can be extended for more real-world considerations.	• What is the impact of additional constraints such as nonlinear transportation cost, environmental impacts, variable demand of byproducts, and multiple sourcing of raw materials on the performance of multiechelon Sugarcane Supply Chain Network (SSCN) to handle the byproducts yielding from the sugarcane industry?

5.4 Cluster 4: Circularity Aspects

Within this content analysis cluster, we delve into diverse dimensions of circularity explored in the literature by leveraging metaheuristics to tackle supply chain optimization challenges. A comprehensive collection of 22 articles has been meticulously curated within this cluster. The findings and insights derived from extensive analysis of most cited articles under this cluster pave the way for novel strategies and future research directions in this domain.

The study by Govindan et al. (2014), which received 410 citations, introduced an innovative model to design a sustainable network for transporting perishable food items. The model takes into account the ecological impact of carbon emissions by incorporating it into its objective function. The researchers presented a cutting-edge optimization model called the "two-echelon location–routing problem with time windows (2E-LRPTW)", which aims to optimize economic and environmental objectives within a perishable food supply chain network. To tackle this problem, they proposed a unique hybrid approach called MHPV that combines two well-known multiobjective algorithms, "adapted multiobjective variable neighborhood search (AMOVNS)" and "multiobjective particle swarm optimization (MOPSO)." Furthermore, the study conducted a comparative analysis of MHPV against other commonly used genetic algorithms based on metaheuristics, namely, MOGA, NSGA-II, and NRGA. The results clearly demonstrated that the proposed method outperforms the alternatives, and the crowding distance method for leader selection showcased superior performance compared to the previous Grids method.

Chouinard et al. (2008), with 62 citations, put forth an innovative model based on stochastic programming to devise logistics networks that seamlessly integrate reverse logistics into existing supply chains. The study conducted a comprehensive assessment of the impacts of uncertainties pertaining to processing, recovery, and demand volumes on the decision-making process for network design. Furthermore, the investigation delved into the strategic positioning of service centers, processing facilities, and warehouses, explicitly focusing on products that have the potential for reuse and determining site missions and product accessibility. The authors advocated for the directed routing of recovered products toward suitable processing alternatives, taking into consideration the varying conditions of the products and the network itself. Additionally, the authors introduced the concept of meeting specific end-user requirements, management policies, and strategies to allocate portions of demand to valorized products. By implementing this analysis, they successfully enhanced the accessibility of valorized products while concurrently reducing the overall operational costs of the network. To unravel the problem, the authors devised a novel heuristic method based on the sample average approximation, incorporating Monte Carlo sampling techniques. Finally, the authors presented computational results and conducted an in-depth analysis of a particular case study considering these findings.

Alshamsi and Diabat (2017), with 56 citations, devised a cutting-edge genetic algorithm (GA) that offers an efficient solution to a complex reverse logistics (RL) challenge on a significant scale. The study successfully employed the GA approach to ascertain the capacity of critical nodes and optimal positioning within the RL network, explicitly focusing on household appliances in the "Gulf Cooperation Council" (GCC) region. To simplify the problem, the authors implemented a coding technique that effectively reduced the number of variables and constraints involved. Additionally, the authors provided valuable insights into the practical aspects of the problem and highlighted key factors for assessing the performance of their heuristic method. They demonstrated the effectiveness of their approach by solving both small and large RL problems to near optimality or with a marginal gap not exceeding 1.5%, all while outperforming the GAMS solver in terms of speed.

With an impressive count of 51 citations, Bányai et al. (2019) thoroughly analyzed how Industry 4.0 approaches can revolutionize waste collection methods and unlock their untapped optimization potential. The authors conceptualized the waste collection norms in urban centers as a dynamic cyber-physical system. They put forth a sophisticated mathematical model that addresses various challenges, such as routing, assignment, and scheduling. The study explicitly defines the objectives of the model, which encompass the efficient allocation of waste sources to garbage trucks and the development of optimal schedules for waste collection, all with the overarching goal of minimizing operational costs, enhancing reliability, and prioritizing comprehensive environmental indicators that have a substantial impact on public health. The authors introduced a novel approach known as the binary bat algorithm to optimize the waste collection process. Additionally, the study rigorously validated the performance of their model through extensive scenario analysis, thereby evaluating its cost efficiency and ability to promote environmental awareness.

In their research, Chouhan et al. (2020), a work acknowledged with 24 citations, introduced an innovative method for gathering "end-of-use" and "end-of-life" products directly from end users, potentially significantly decreasing the overall expenditure of the supply chain. To evaluate the total cost of the supply chain, the study devised a mixed-integer linear programming model and put forth various metaheuristics and hybrid strategies as alternative solution methodologies. To assess the best combinations of algorithm parameters, the Taguchi method was employed. Furthermore, the article generated problem instances to confirm the effectiveness of the proposed model in a real-world scenario.

With 22 citations, Soleimani et al. (2022) presented an innovative and environmentally conscious closed-loop supply chain model that optimizes overall profitability, energy consumption, and job creation. This model encompasses various entities, such as manufacturers, suppliers, distribution centers, disposal centers, and customer zones, and offers three distinct options for handling returned items: remanufacturing, recycling, or disposal. The proposed model addresses customer demand and tackles real-world limitations associated with allocation, inventory, and location decisions within a CLSC framework. Moreover, the paper introduces a collection of efficient "Lagrangian relaxation reformulations" and rapid heuristics designed to solve a practical numerical instance. The results highlight the applicability of the obtained solution and underscore the remarkable efficiency of the devised solution algorithm in solving complex supply chain models. By proposing a sustainable CLSC model that considers multiple objectives and real-life constraints and provides effective solution algorithms for managing large-scale problems, this paper significantly contributes to the current literature in the field.

A separate investigation conducted by Chekoubi et al. (2022), which has only been referenced in two other studies, introduced mathematical models specifically designed to address the intricate planning challenges associated with integrated production, inventory, and direct-reverse distribution operations within closed-loop supply chains that incorporate the remanufacturing option. The authors devised optimization strategies that work collaboratively to minimize production inventory, setup, and routing costs. Furthermore, the study approached the complex "Integrated Production-Inventory-Routing Problem with Remanufacturing" (IPIRP-R), effectively managing reverted "End-Of-Life" (EOL) products. The authors developed a "two-phase decomposition heuristic" to solve the proposed model iteratively. Notably, the study successfully achieved simultaneous optimization of the "Vehicle Routing Problem with Simultaneous Pick-up and Delivery" (VRPSPD) and the "Capacitated Lot-Sizing Problem with Remanufacturing" (CLSP-R) options within a single comprehensive framework. The authors presented highly satisfactory solutions for small and moderate-scale instances within a reasonable computational time, particularly when confronted with challenges involving substantial manufacturing and remanufacturing costs alongside comparatively low pick-up requests. Table 7 below lists the proposed research questions identified under this cluster.

Table 7: Future research opportunities identified under cluster 4

Identified research gap	**Future research opportunities**
1. There is a need to explore newer metaheuristics strategies in the network design for a sustainable perishable food supply chain.	• How do parallel, nested, or cooperative metaheuristics strategies affect the sustainable supply chain network design considering carbon emissions in the objective function?
2. Additional considerations are required to improve design decisions in the logistics network, which integrates reverse logistics into the existing supply chain.	• What is the impact of additional factors such as uncertainties, types of recovery processes, environmental regulations and policies, multiple periods, and dynamic demand on the design decisions in the logistic network

	integrating reverse logistics into the current supply chain?
3. Optimization models designed for large-scale reverse logistics problems should be extended for more practical considerations.	• How do reverse logistics policy, demand and return rate uncertainties, carbon emission, social responsibility, multiproduct, and multiechelon networks affect the model's performance for reverse logistics network design?
4. Future research should incorporate Industry 4.0 techniques in waste collection solutions.	• How can the Internet of Things (IoT) and Big Data complement waste collection solutions?
5. Extending existing waste collection solutions for more practical requirements is necessary.	• What is the impact of weather conditions, traffic congestion, waste collection policies (such as pay-as-you-throw), and recycling incentives on the efficiency of waste collection solutions?
6. There is a need to investigate the impact of data-driven technologies on collecting and handling end-of-life products.	• How does the decision-support system enable companies to make better decisions regarding "end-of-life" and "end-of-use" products?
7. The Lagrangian reformulation used for a sustainable CLSC model should be compared with other variants.	• How does a Benders decomposition reformulation compare to a Lagrangian reformulation in designing a sustainable CLSC that considers manufacturers, suppliers, disposal centers, and distribution centers?
8. The model attempting to solve the "Integrated Production-Inventory-Routing Problem with Remanufacturing" (IPIRP-R) can be extended by considering additional requirements.	• How can the mathematical model designed for IPIRP-R formulation be improved by considering greenhouse gas emissions from production, remanufacturing, routing, and inventory handling activities?

6. Discussion

Numerous metaheuristic methods have been employed to address the CLSC or reverse logistics network design problem. It's important to highlight that a considerable number of studies have utilized these metaheuristics in their standard form or with slight modifications. Additionally, more sophisticated optimization algorithms, such as adaptive algorithms, self-adaptive algorithms, island algorithms, polyploid algorithms, and hyper-heuristics, have been applied to address unique decision-making challenges in supply chain network design. Dulebenets et al. (2018) suggested an evolutionary algorithm that adjusts itself to solve the issue of planning when ships should dock at marine container terminals. This problem is seen as a mixed integer linear programming (MILP) model, and the objective is to make the overall time ships spend at the terminal as short as possible while minimizing instances where ships leave late. The research checked how well this solution worked by comparing it with different evolutionary algorithms. The study's outcomes show that the method of changing certain parameters by itself noticeably makes the final results better without too much alteration in the computational time. Dulebenets (2021) introduced a fresh approach, the Adjustable Polyploid Memetic Algorithm (APMA), designed to arrange the movement of trucks at a junction point for efficient truck operations scheduling. The article illustrates how the algorithm manages the number of chromosome duplicates by utilizing the adaptable polyploid mechanism, which is determined by enhancements in the goal accomplishment and adjustments in the time taken for computations. The research also applied specialized hybridization methods specific to the issue and incorporated them into the algorithm to make the search process smoother. The APMA algorithm developed in this paper substantially surpasses certain widely known metaheuristics in terms of the quality of the solutions it provides and generates truck schedules with lowered total expenses for truck services. Zhao and Zhang (2020) proposed a method that uses learning to make multiobjective optimization problems work better. The research uses learning automation (LA) to change how the method evolves strategies to match the particular problem. The researchers used an external archive to keep track of solutions that are not dominated by others according to Pareto rules. They also devised a way to adjust certain reference points to improve the ability to solve problems where the Pareto front (PF) is unclear or made up of separate points. The researchers were successful in obtaining good results in terms of reaching a solution and getting close to the real Pareto front.

Pasha et al. (2022) introduced an innovative way to tackle the complex challenge of efficiently routing vehicles in a scenario where entire factories can be transported – a concept known as "factory-in-a-box." This ground-breaking approach does not stop at traditional manufacturing; it accounts for the unique choice between factory-in-a-box production and conventional manufacturing, all tailored to individual customers. This study focuses on making the best decisions for vehicle selection and crafting optimal routes in a dynamic supply chain. This chain involves a central depot, various suppliers, manufacturing units, and end customers. The authors go beyond conventional methods by unveiling a specially crafted hybrid metaheuristic that facilitates directly integrating problem-specific characteristics into the solution-seeking process. The proposed approach underwent rigorous testing in a real-world application involving a vaccination project. The findings of this case study shed light on the algorithm's prowess, as it outperformed other conventional methods. Gholizadeh et al. (2021) put forth an ingenious preventive maintenance (PM) approach that does not merely focus on finding the most efficient sequence for task execution; it delves into the realm of uncertainty by considering the uncertain nature of task processing times. To tackle this, the researchers harnessed the power of robust optimization models, creating a solid framework to handle the challenge. The authors introduced a cutting-edge, scenario-based genetic algorithm to tame the complexity of the model. To demonstrate the practicality of their approach, they applied it to a real-world scenario—a waste to energy (WTE) system in Iran. The outcomes were not impressive, showcasing the real-world value of this research. Furthermore, the study compared this method with an exact optimization technique and a conventional genetic algorithm. The newly introduced approach outperformed the competition in terms of time saved and the cost-effectiveness it brings to the table through the PM policy. Hence, such advanced metaheuristics spark exciting possibilities for future research. These algorithms hold the key to shaping decisions around reverse and circular supply chain network design, promising a future where efficiency and innovation harmoniously intertwine.

Subsequently, we delve into how this study has effectively approached the research inquiries introduced in the initial section and the formulation of a ground-breaking conceptual framework derived from the invaluable insights gained throughout the research process. Supply chain management encompasses numerous challenges typically explored within the realms of strategic, tactical, and operational decision-making stages. In the context of promoting circularity, the application of metaheuristics has gained significant traction in resolving diverse optimization challenges. Building upon the insights gleaned from our meticulous content analysis, it is evident that the location inventory routing problem (LIRP) (Yuchi et al., 2021), vehicle routing problem (VRP), supply chain network design (SCND), location-allocation problem (LAP), production routing problem (PRP), location inventory problem (LIP) (Asl-Najafi et al., 2015), and production inventory routing problem (PIRP) stand as the most extensively researched issues residing at the intersection of closed-loop supply chain/reverse logistics and metaheuristics. Engaging in the discourse surrounding the resolution of conventional supply chain optimization challenges within the context of reverse logistics (Anbuudayasankar et al., 2010; Khawam et al., 2007; Kim and Lee, 2013) and closed-loop supply chains (Shabbir et al., 2021; Zhang et al., 2022) using metaheuristics has enabled us to address and provide insights into our inquiry, Research Question 1.

During our extensive literature review, we have unearthed compelling evidence showcasing the existence of various single-objective pure metaheuristics, including the genetic algorithm (GA), variable neighborhood search (VNS), simulated annealing (SA), particle swarm optimization (PSO) (Asghari et al., 2022), tabu search (TS), Keshtel algorithm (KA) (Liao et al., 2020), red deer algorithm (RDA) (Fathollahi-Fard et al., 2021) and water wave optimization (WWO). Moreover, we also identified additional metaheuristics, such as the "nondominated sorting genetic algorithm" (NSGA-II) and multiobjective gray wolf optimizer (MOGWO), that fall within the pure metaheuristics category, serving as potent tools for tackling multiobjective optimization modeling. As we delved into the reviewed literature, we uncovered intriguing instances of hybrid metaheuristics, such as the imperialist competitive algorithm (ICA). Furthermore, we encountered the Hybrid RDSAGA, which skillfully blends the red deer algorithm, simulated annealing, and genetic algorithm. Additionally, we encountered the KAGA, a novel combination of the Keshtel algorithm and genetic algorithm. Further exploration led us to the GASA, a hybridization venture that fuses the genetic algorithm with simulated annealing, and the KASA, an innovative hybrid approach that combines the Keshtel algorithm with simulated annealing. These diverse hybrid metaheuristics exemplify the creative integration of algorithms to unlock new possibilities in optimization and problem-solving domains. By means of this comprehensive categorization of metaheuristics and their respective applications, we have successfully addressed and provided conclusive answers to our second research inquiry, Research Question 2.

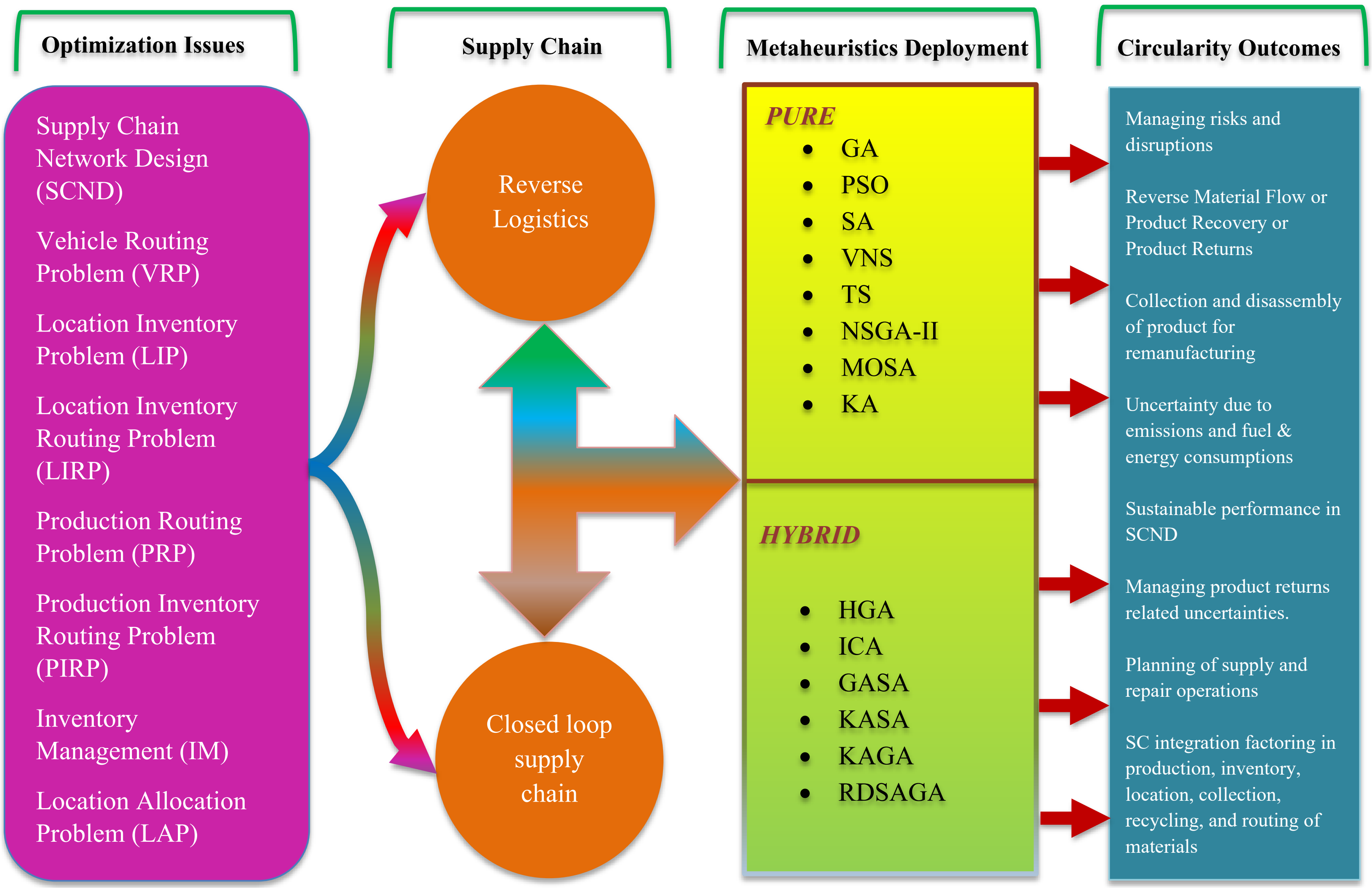

Figure 9: Conceptual framework

Subsequently, our in-depth descriptive and content analysis of the literature revealed a range of circularity aspects, including effective risk and disruption management, intricate dynamics of reverse material flow, strategic handling of product returns (Fazle Baki et al., 2014), efficient product recovery techniques, streamlined processes for collection and disassembly of products to facilitate remanufacturing (Kim et al., 2018), handling uncertainties stemming from emissions and fuel/energy consumption (Leng et al., 2019; Mehrbakhsh and Ghezavati, 2020), fostering sustainable performance in supply chain network design (SCND), navigating uncertainties associated with product returns (Guo et al., 2020), optimizing supply and repair operations, and achieving a seamless integration of key supply chain elements encompassing location, production, inventory, collection, recycling, and material routing. The literature underscores the transformative potential of these optimization techniques in promoting circularity (Mishra et al., 2023) in supply chain operations. Through an in-depth exploration of the various dimensions of circularity utilizing the perspective of metaheuristics, we have gained the necessary insights to respond effectively to our third research inquiry, Research Question 3.

Moreover, we introduce an inventive conceptual framework that has been meticulously crafted, drawing insights from our comprehensive descriptive and content analysis of scholarly works. As depicted in Figure 9, this framework comprises four foundational pillars that encapsulate the utilization of metaheuristics within closed-loop supply chains and reverse logistics. These four pillars encompass various essential elements, including optimization concerns, the nature of the supply chain, the specific metaheuristic techniques employed, and the resulting circularity outcomes.

7. Conclusion

Our study's main objective is to comprehensively review the literature on metaheuristics in the context of circularity. To achieve this, a curated collection of articles was compiled by extracting data from two distinct sources using a combination of targeted keywords as the search criteria. The initial search yielded a total of 230 articles published up until 2023. Subsequently, a rigorous article screening process was conducted, considering factors such as subject relevance, article type, and abstract examination. Following this phase, the number of articles was narrowed down to 77. A descriptive bibliometric analysis was performed on the screened articles to gain deeper insights into the field, focusing on various classification criteria such as publication trends over the years, top journals, leading publishers, prominent authors, subject areas, and geographical distribution. Moreover, an extensive content analysis was conducted on the most highly cited articles within each identified cluster, covering four key dimensions: supply chain types, specific supply chain problems addressed, types of metaheuristics employed, and circularity aspects. We also proposed a conceptual framework based on the outcomes of the descriptive analysis and the insights derived from the content analysis.

7.1 Theoretical and Practitioner Implications

The study holds significant implications for various stakeholders, including researchers, experts, and industry professionals. This systematic exploration of the literature, shedding light on the role of metaheuristics in fostering circularity, will greatly contribute to endeavors centered around sustainability, achieving carbon neutrality, and advancing research related to the environment. The descriptive analysis facilitated a comprehensive understanding of the growth patterns and underlying trends within the realm of metaheuristics research in the circularity context, providing valuable guidance to researchers and stakeholders alike.

Notably, the cluster-based content analysis yielded promising opportunities for future research within each cluster, serving as an essential reference for subsequent research endeavors focused on applying metaheuristics in the context of circular supply chain intelligent systems. The developed framework will enhance the comprehension of supply chain optimization challenges, metaheuristics characterization, and potential circularity outcomes. Consequently, the outcomes of this study will foster a deeper understanding and open avenues for further advancements in applying metaheuristics in the circularity context.

7.2 Limitations and future perspective

Similar to any research endeavor, our study is not exempt from certain limitations. The compilation of articles relied on the chosen database and the specific keywords employed in the search string. Consequently, there is a potential risk of overlooking relevant articles that may not have surfaced due to the limitations of the selected database or the specific terms used in the search string. The insights garnered from the content analysis are contingent upon our interpretation of the reviewed literature and the arguments presented therein, which may undergo variations in future studies of a similar nature. Furthermore, we hold the view that the intricacies of complexity theory (Pereira et al., 2013) and the "no-free lunch" theory (Sterkenburg and Grünwald, 2021) in optimization hold the potential to elucidate the intricacies of supply chain operations and the diverse presence of metaheuristics within the supply chain domain. The conceptual framework proposed in this study is a direct outcome of the descriptive and content analyses conducted. However, it is imperative to acknowledge that this framework necessitates further validation and testing within a real-world context, which can be accomplished in subsequent studies.

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