

Recent advances in multi-criteria decision-making approaches for circular supply chains: A comprehensive review



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Abstract This review article explores the pivotal role of multi-criteria decision making (MCDM) in optimizing circular supply chains (CSC). MCDM methodologies are vital for navigating the complex decision-making scenarios inherent in CSC, where multiple conflicting criteria must be simultaneously addressed. This comprehensive review highlights the commonly employed MCDM methodologies and their applications within CSC, underscoring their potential to enhance sustainability and efficiency. The increasing academic interest in MCDM within supply chain management (SCM) is evident from the publication trends, which show a significant rise from 2000 to 2024. This review focuses into the specific challenges faced by CSCs, such as resource scarcity, waste management, and environmental impact. By integrating MCDM approaches, organizations can better prioritize and balance these competing demands, leading to more resilient and adaptive supply chains. The review emphasizes the importance of a holistic approach, considering economic, environmental, and social dimensions to achieve truly sustainable supply chains. Moreover, the article explores various MCDM methodologies where each methodology's application in CSC is examined, demonstrating their effectiveness in addressing sustainability, efficiency, and risk management challenges. The review concludes that MCDM methodologies are crucial for achieving balanced and sustainable outcomes in CSC. With ongoing technological advancements and a deeper understanding of CSC dynamics, the future of MCDM research in this field appears promising. Overall, this comprehensive review provides valuable insights into the current state and future prospects of MCDM in CSC, highlighting its critical role in driving sustainable development. Overall, this comprehensive review provides valuable insights into the current state and future prospects of MCDM in CSC, highlighting its critical role in driving sustainable development.

Keywords: circular economy, AHP, ANP, TOPSIS, DEMATEL, ELECTRE

1. Introduction

The concept of a circular supply chain (CSC) has gained significant attention in recent years as a sustainable alternative to traditional linear supply chains. Unlike the linear model, which follows a “take-make-dispose” approach, CSC aim to close the loop by reusing, refurbishing, and recycling materials and products. This shift is driven by the need to reduce waste, enhance resource efficiency, and minimize environmental impacts (Montague, 2023). The transition to CSC is essential for achieving sustainable development goals and addressing the growing concerns over resource depletion and environmental degradation (Filho et al., 2022).

CSC integrate forward and reverse logistics to create a seamless flow of materials. This integration is crucial for maintaining the value of products and materials for as long as possible, thereby contributing to a more sustainable economy (Rodrigue, 2024). The principles of CSC include designing products for longevity, establishing reverse logistics networks, and implementing advanced technologies for tracking and managing materials (Macarthur, 2019). These principles not only help in reducing waste but also in creating economic value through the efficient use of resources (Sarkis, 2023). The implementation of CSC involves several key strategies. First, products must be designed with their entire lifecycle in mind, ensuring they are durable, repairable, and recyclable (Giudice et al., 2021). This approach not only extends the product's life but also facilitates easier disassembly and recycling at the end of its life. Second, reverse logistics systems must be established to efficiently collect and process used products and materials. This includes setting up collection points, transportation networks, and processing facilities to handle returned goods (Vyas & Yadav, 2024; Moula et al., 2017).



The primary objective of this review article is to explore the role of multi-criteria decision making (MCDM) in optimizing circular supply chains (CSC). MCDM methodologies are essential for addressing the complex decision-making scenarios that arise in CSC, where multiple conflicting criteria must be considered simultaneously. This review aims to provide a comprehensive overview of the commonly used MCDM methodologies and their applications in CSC. By doing so, it seeks to highlight the potential of MCDM in enhancing the sustainability and efficiency of CSC (dos Santos Gonçalves & Campos, 2022; Orji & Ojadi, 2022). MCDM methodologies are particularly valuable in CSC due to the multifaceted nature of sustainability challenges. These methodologies allow decision-makers to evaluate various alternatives based on multiple criteria, such as cost, environmental impact, and social implications. This holistic approach ensures that decisions are made considering all relevant factors, leading to more balanced and sustainable outcomes (Farooque et al., 2019; Toffel, 2004).

MCDM has found extensive applications across various fields, including engineering (Rahardjo et al., 2023; Farughi and Mostafayi, 2017; Toffel, 2004; Purwani et al., 2024; Noor et al., 2019; Ramanathan et al., 2023), agriculture (Agnusdei et al., 2023; Elhidaoui & Kota, 2023; Kumar et al., 2021), healthcare (Qu et al., 2020; Tseng, 2022), and others (Zaman et al., 2023; dos Santos Gonçalves & Campos, 2022). In engineering, MCDM aids in design optimization, resource allocation, and project management, enabling teams to weigh multiple factors such as cost, performance, and safety. In healthcare, MCDM supports clinical decision-making, patient prioritization, and resource distribution, helping to optimize outcomes while considering patient needs and system constraints. In the service industry, MCDM assists in service quality evaluation, customer satisfaction assessments, and strategic planning, ensuring that businesses can align their offerings with consumer expectations.

The review will cover several widely used MCDM methodologies, including the Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Decision-Making Trial and Evaluation Laboratory (DEMATEL), and Elimination and Choice Expressing Reality (ELECTRE) methods. Each methodology will be discussed in terms of its principles, applications, and advantages in the context of CSC. By examining these methodologies, the review aims to provide insights into how MCDM can be effectively applied to optimize various aspects of CSC, such as supplier selection, product design, and logistics management. The ultimate goal is to demonstrate the potential of MCDM in supporting the transition to more sustainable and efficient supply chains.

The remainder of the article is structured as follows: Section 2 describes the concepts of the CSC and its models. Section 3 provides an overview of the commonly used MCDM methodologies and examines their applications within the CSC. In Section 4, the publication trend is discussed in detail. Consequently, the challenges and opportunities in MCDM for the CSC are discussed in Section 5. The paper concludes in Section 6.

2. Circular Supply Chain Concepts and Models

The Circular Supply Chain (CSC) is a vital component of the Circular Economy (CE), as both aim to minimize waste and maximize resource efficiency. In traditional supply chains, resources move in a linear fashion—from extraction, through production and consumption, to eventual disposal. In contrast, a CSC supports the CE by keeping products, materials, and resources in continuous circulation through reuse, recycling, and remanufacturing. This closed-loop system is central to the CE's core principles of reducing waste, extending the lifespan of materials, and regenerating natural systems. By adopting CSC practices, businesses can reduce their environmental footprint, enhance resource efficiency, and build sustainable, profitable business models within the CE framework.

While there is no single, universally accepted definition of the Circular Economy (Kirchherr et al., 2017), the definition from the Ellen MacArthur Foundation is widely recognized: "an industrial economy that is restorative or regenerative by intention and design" (Ellen MacArthur Foundation, 2013). The CE emphasizes resource efficiency, waste reduction, and recycling (Kirchherr et al., 2017), aiming to improve the Earth's ecosystems while supporting profitable business models. However, the environment's capacity, known as assimilative capacity, to absorb waste and transform it into safe or useful resources is limited. As long as waste remains within this capacity, the ecosystem can regenerate itself effectively. But exceeding this limit, or over-extracting resources will damage the ecosystem's ability to recover, resulting in a reduction of available resources, as illustrated in Figure 1.

CSC represent a transformative approach to traditional SCM, emphasizing the continuous use of resources through recycling, remanufacturing, and reuse. This paradigm shift is driven by the need to address environmental sustainability and resource efficiency. The concept of CSC integrates principles from the circular economy, which aims to minimize waste and maximize resource utilization (Montague, 2023).

Key models in CSC include closed-loop supply chains, which focus on the return and reuse of products and materials, and industrial symbiosis, where waste from one process becomes input for another. These models are supported by various strategies such as product life extension, resource recovery, and sustainable product design. For instance, the closed-loop supply chain model has been extensively studied in the context of electronic waste management, where the recovery of valuable materials is critical (Rahardjo et al., 2023).

Implementing CSC requires a comprehensive understanding of the entire product lifecycle, from design to disposal. This involves the integration of various stakeholders, including manufacturers, suppliers, consumers, and recyclers. Effective

collaboration among these stakeholders is essential for the successful implementation of CSC (Laura et al., 2007). Additionally, advanced technologies such as the Internet of Things (IoT) and blockchain can enhance transparency and traceability in CSC.

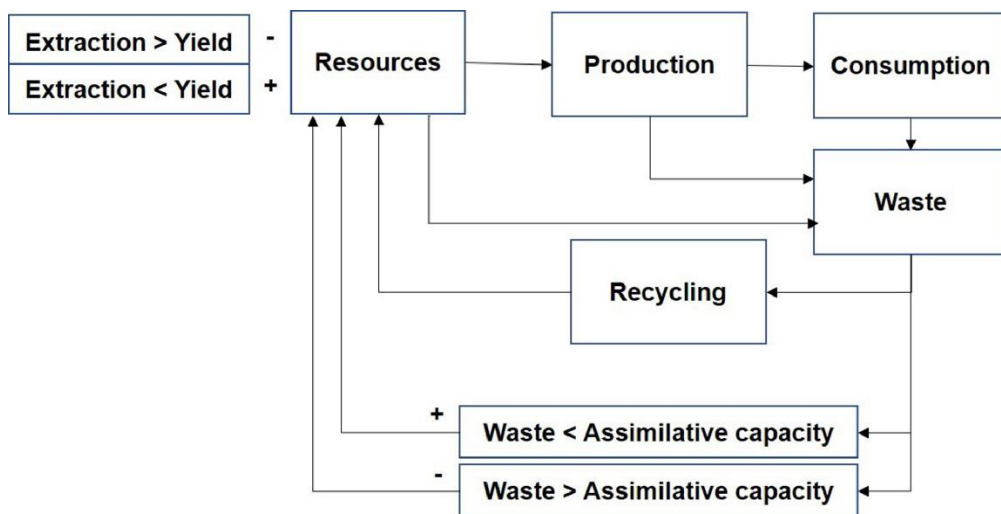


Figure 1 Model of circular economy. Source: Vegter et al. (2020).

As illustrated by Farooque et al. (2019) in Figure 2, a typical (linear) supply chain (Figure 6(a)), a closed-loop supply network (Figure 2(b)) and a circular supply chain (Figure 2c) are contrasted. In a linear supply chain, resources from the biosphere and geosphere are extracted, and waste, packaging, and end-of-life products are discarded at various points along the supply chain, often ending up in landfills. Compared to traditional production, closed-loop remanufacturing of photocopiers can save 20–70% of materials, labor, and energy, and minimize waste by 35–50% (Toffel, 2004). However, because efforts are concentrated within the producer’s supply chain and do not engage new auxiliary channel members or supplementary supply chains, the level of value recovery in a closed-loop supply chain is often constrained (Moula et al., 2017). Even with a closed-loop supply chain, significant waste is still produced because it is rarely possible to recycle or reuse every undesirable item within the same supply chain.

By working with other organizations in the same industry sector (open loop) or with different industries (cross-sector) to recover value from waste, a circular supply chain goes beyond. Because a circular supply chain is intended to systematically renew and replenish resources in the industrial and natural ecosystem in which it is embedded, it should ideally produce zero waste. As shown in (Figure 5c), there are two types of resource flows in CSC: primary resource flows and circular resource flows.

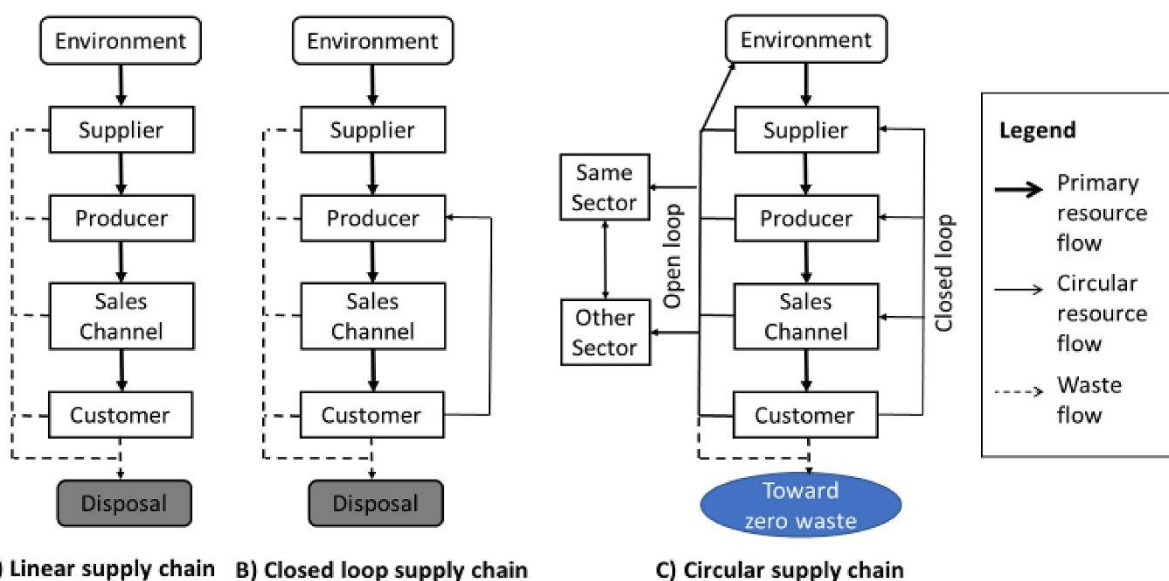


Figure 2 Overall flow of (a) Linear supply chain; (b) Closed loop supply chain; and (c) Circular supply chain. Source: Farooque et al. (2019).

Advanced technologies play a critical role in the successful implementation of CSC. For instance, the use of Internet of Things (IoT) devices and blockchain technology can enhance the traceability and transparency of materials throughout the supply chain. IoT devices can monitor the condition and location of products in real-time, while blockchain can provide a secure



and immutable record of transactions. These technologies help in ensuring that materials are properly tracked and managed, reducing the risk of waste and inefficiency.

Moreover, the adoption of CSC can lead to significant economic benefits. By reusing and recycling materials, companies can reduce their reliance on virgin resources, which are often more expensive and subject to price volatility. This not only lowers costs but also enhances the resilience of the supply chain against disruptions. Additionally, CSC can open up new revenue streams through the sale of refurbished products and recycled materials.

The environmental benefits of CSC are also substantial. By keeping materials in use for longer, CSC can significantly reduce the environmental footprint of products. This includes lower greenhouse gas emissions, reduced energy consumption, and less waste sent to landfills. Furthermore, CSC contribute to the conservation of natural resources by reducing the need for raw material extraction.

In summary, the transition to CSC is essential for achieving sustainability goals. By integrating forward and reverse logistics, promoting the design of durable products, and leveraging advanced technologies, businesses can reduce waste, enhance resource efficiency, and minimize environmental impacts. The principles and strategies of CSC not only help in creating a more sustainable economy but also offer significant economic and environmental benefits.

3. Addressing Circular Supply Chain Issues using MCDM Methodologies

MCDM methodologies are essential tools for evaluating and prioritizing multiple competing criteria in decision-making processes. These methodologies help decision-makers to systematically analyze complex problems, considering various factors and their interrelationships. In the context of CSC, MCDM methods are particularly valuable for assessing sustainability, efficiency, and risk management. This section explores the most commonly used MCDM methodologies in Supply Chain Management, with a focus on selected key techniques that have gained significant attention in the literature, as summarized in Table 1. It provides an overview of their methodologies and applications in CSC.

Table 1 Most commonly used MCDM methodologies.

MCDM methodologies	Description
Analytic Hierarchy Process (AHP)	Analyzes multiple criteria by structuring the problem hierarchically and prioritizing criteria through pairwise comparisons based on expert judgments.
Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)	Identifies solutions from a finite set of alternatives based on their geometric distance from an ideal solution.
Decision-Making Trial and Evaluation Laboratory (DEMATEL)	Analyze and model complex causal relationships among factors in a system, transforming relationships into a cause-effect group.
Elimination and Choice Expressing Reality (ELECTRE)	Based on the concept of outranking, where alternatives are compared pairwise to determine their relative performance.
Analytic Network Process (ANP)	Extended and more general form of the AHP that structures a decision problem as a network and enables feedback and interactions within and between clusters.

3.1. AHP methodology and applications in CSC

The AHP has been extensively applied in CSC to address various challenges and enhance sustainability. One significant application is in evaluating sustainable supply chain practices. Researchers have utilized AHP to prioritize different sustainable practices, with a particular emphasis on recycling and waste management. By systematically comparing various practices, AHP helps decision-makers identify the most impactful actions to improve sustainability within supply chains (Mu et al., 2017; Brunelli, 2014).

In the realm of risk management, AHP has proven to be a valuable tool. Researchers have applied AHP to identify and prioritize risks in CSC. This approach aids companies in mitigating potential disruptions by focusing on the most critical risks. By structuring the decision-making process, AHP enables a comprehensive evaluation of risks, ensuring that companies can develop effective risk management strategies (Saaty, 2001).

Supplier selection is another area where AHP has been effectively employed. In CSC, selecting suppliers that align with sustainability criteria is crucial. AHP facilitates this process by evaluating and ranking suppliers based on various sustainability factors. This ensures that companies can choose suppliers who support their circular economy goals, thereby enhancing the overall sustainability of the supply chain (Alkheder et al., 2023; Erdinç et al., 2024). Performance measurement in CSC has also benefited from the application of AHP. Researchers have used AHP to develop frameworks for measuring the performance of CSC. These frameworks consider multiple criteria, including environmental and economic performance, providing a holistic view of the supply chain's effectiveness. By using AHP, companies can identify areas for improvement and track their progress towards sustainability goals (Petrillo & Karpak, 2021).

Finally, AHP has been instrumental in supporting strategic decision-making in CSC. By structuring complex decisions and providing a clear prioritization of alternatives, AHP helps companies choose the most effective strategies for implementing

circular economy principles. This strategic support is crucial for companies aiming to transition to more sustainable and circular supply chain models (Sharma et al., 2022). Table 2 encapsulates the latest findings regarding CSC through the application of the AHP method.

Table 2 Recent research on CSC based on AHP.

Authors	Remark	Research problem	Research aims	Methodology/ technique	Main finding
Lahane and Kant (2021)	The paper investigates challenges in circular supply chain implementation using Pythagorean Fuzzy AHP approach, showcasing AHP's relevance and effectiveness in addressing complexities within CSC.	- Lack of research on barriers to circular supply chain (CSC) adoption in emerging economies, especially in India - Need to identify and analyze the relationships between the barriers to CSC implementation.	- Identified the barriers to Circular Supply Chain (CSC) implementation - Analyzed the inter-relationships among the CSC barriers - Determine the impact of these barriers on CSC implementation.	Utilized Pythagorean Fuzzy AHP approach for analysis.	Implementation challenges in circular supply chain has been addressed.
Lahane and Kant (2023)	The paper utilizes Pythagorean fuzzy AHP to assess barriers in CSC implementation, highlighting the importance of top management support and the challenges of product acceptability.	Lack of understanding of the challenges to CSC implementation in the Indian manufacturing sector.	To explore and evaluate the challenges to circular supply chain (CSC) implementation in the Indian manufacturing sector. To identify 24 CSC challenges through literature review and expert input.	Pythagorean fuzzy AHP (PF-AHP). Pythagorean fuzzy decision making trial and evaluation laboratory (PF-DEMATEL).	Based on the study, "Lack of top management support" is the most crucial barrier and "Low acceptability for remanufactured products" is the least significant barrier.
Tavana et al. (2023)	The paper integrated fuzzy inference and best-worst method for sustainable supplier selection in CSC, enhancing decision-making by considering economic, social, circular, and Industry 4.0 perspectives.	Selecting sustainable suppliers with zero waste in CSC. Consider socio-economic and environmental factors in supplier selection process.	Assessment of sustainable suppliers in intelligent CSC. Demonstrate method using data from an offshore wind farm.	Fuzzy group best-worst method for weighting sub-criteria. Fuzzy inference system for ranking and selecting suppliers.	Integrated method for sustainable supplier selection in CSC. Demonstrated applicability using data from an offshore wind farm.



Tushar et al. (2022)	The study employs FAHP in circular supplier selection for construction in emerging economies, emphasizing criteria like pollution control and green practices, enhancing sustainability in supply chains.	Circular supplier selection in construction industry of emerging economies. Integrating sustainability principles into supplier selection criteria in construction industry.	Explored circular supplier selection in construction industry of emerging economies. Boost sustainability in the construction sector through supplier selection.	Fuzzy Analytical Hierarchy Process (FAHP). Preference Ranking Organization Method for Enrichment of Evaluations II (PROMETHEE II).	Top criteria for supplier selection: on-time delivery, conformance, rejection rate. Top circular supplier selection criteria: pollution control, green packaging, regulations.
Otay and Kahraman (2022)	The paper introduced a novel Circular Intuitionistic Fuzzy AHP methodology for supplier evaluation. It combines AHP and VIKOR methods, enhancing decision-making in multi-expert scenarios.	Developed a Circular Intuitionistic Fuzzy AHP-VIKOR methodology. The application focuses on a multi-expert supplier evaluation problem	Applied to multi-expert supplier evaluation problem. Development of C-IF AHP & C-IF VIKOR methodology.	C-IF AHP and C-IF VIKOR	Circular Intuitionistic Fuzzy AHP-VIKOR methodology for multi-expert supplier evaluation. Incorporates uncertainty with C-IFS for decision-making in MCDM methods.
AlKheder et al. (2023)	The paper focused on utilizing AHP to assess complexity in Kuwait's mega construction projects, showcasing its application in project management rather than CSC.	Kuwait megaprojects faced delays and quality issues due to high complexity. AHP was used for complexity measurement model for construction projects to assist decision making process.	Developed complexity measurement model using AHP for Kuwait megaprojects. New Kuwait University campus was used as a case study.	Hybrid FAHP method and Conventional AHP method were used.	Based on the study, "Technological Complexity" scored highest in both AHP and FAHP methods. Varying complexity levels across dimensions were identified in the study.

3.2. TOPSIS methodology and applications in CSC

TOPSIS is a multi-criteria decision analysis method that identifies solutions from a finite set of alternatives based on their geometric distance from an ideal solution. TOPSIS has been widely utilized in CSC to address various challenges and enhance decision-making processes. One significant application of TOPSIS is in performance evaluation. Researchers have used TOPSIS to assess the performance of CSC, with a particular focus on resource efficiency and waste reduction. By comparing different performance metrics, TOPSIS helps decision-makers identify the most efficient and sustainable practices, thereby improving the overall performance of the supply chain (Roghianian et al., 2014).

In the area of supplier selection, TOPSIS has proven to be an effective tool. Researchers have applied TOPSIS to select suppliers that meet circular economy criteria. This method allows companies to evaluate and rank suppliers based on multiple sustainability factors, ensuring that the chosen suppliers align with the company’s circular economy goals. This application of TOPSIS helps companies build more sustainable and resilient supply chains. TOPSIS has also been employed to prioritize



initiatives within CSC. By evaluating various initiatives based on multiple criteria, TOPSIS helps companies identify and focus on the most impactful actions. This prioritization is crucial for effectively implementing circular economy principles and achieving sustainability goals.

Risk assessment is another area where TOPSIS has been effectively utilized. Researchers have used TOPSIS to evaluate and rank risks in CSC. This approach helps companies identify the most critical risks and develop strategies to mitigate them. By providing a structured framework for risk assessment, TOPSIS enhances the resilience and stability of CSC. Finally, TOPSIS has supported strategic decision-making in CSC. By providing a clear ranking of alternatives based on their proximity to the ideal solution, TOPSIS helps decision-makers choose the most effective strategies for implementing circular economy principles. This strategic support is essential for companies aiming to transition to more sustainable and CSC models (Tanveer et al., 2023; Haq and Boddu, 2015). Table 3 outlines recent studies on CSC that are grounded in the TOPSIS methodology.

Table 3 Recent research on CSC based on TOPSIS.

Authors	Remarks	Research problem	Research aims	Methodology/ technique	Main finding
Kacprzak (2021)	The paper introduces an extended TOPSIS method for Group Decision Making with Interval Numbers (IN), enhancing decision-making processes without using aggregation operators, benefiting supply chain decision-making.	Extension of TOPSIS method for Group Decision Making with IN. Avoids aggregation operator, considers all decision makers' evaluations.	Extend TOPSIS method for Group Decision Making with IN. Utilize objective criteria weights without aggregation operator	Extension of TOPSIS method for Group Decision Making. Transformation of decision matrices into criteria and alternative matrices	Method considers all decision makers' evaluations without aggregation operator.
Akmal et al. (2024)	The research paper utilizes the TOPSIS method to prioritize coffee bean suppliers based on criteria like quality, price, and delivery accuracy, aiding in effective supply chain decision-making.	Determining the best coffee bean supplier using TOPSIS method.	Determine best coffee bean supplier using TOPSIS method	TOPSIS method used for supplier selection based on criteria weight.	Supplier 4 is the best with a preference value of 0.6315.
Haq and Boddu (2015)	An integrated fuzzy QFD and TOPSIS approach is proposed to identify the most viable lean enablers to enhance leanness in supply chain.	Identification of lean enablers within SCM	The objective is to identify the most viable lean enablers (LEs) to achieve the required lean attributes (LAs) in the supply chain.	- Integrated TOPSIS and QFD approach - Use of fuzzy logic to deal with imprecise and vague decision-making problems - Case study from the Indian food processing industry to illustrate the proposed methodology	The approach uses fuzzy logic to deal with the imprecision and vagueness in the decision-making process. - The proposed methodology is illustrated through a case study from the Indian food processing industry.
Roghianian et al. (2014)	The paper applies fuzzy TOPSIS to rank suppliers in the food industry supply chain.	Not mentioned (the abstract does not suggest any research gaps or unanswered questions that the study aims to address)	To identify different suppliers for a food industry company and to evaluate and rank these suppliers using the Fuzzy	- Determining different suppliers - Identifying various criteria to evaluate the suppliers - Applying the Fuzzy TOPSIS approach to	- The study used the Fuzzy TOPSIS method to rank different suppliers in the food industry based on various criteria.



			TOPSIS method and various criteria.	rank the different supplier alternatives.	
Tanveer et al. (2023)	A fuzzy TOPSIS model is used to evaluate and rank digital technologies (CPS, IoT, CM, BDA) for their impact on circular supply chain infrastructure in SMEs.	Not mentioned (the abstract does not explicitly mention any research gaps or unanswered questions)	The study collected employee preferences on CSC management criteria, including profit, innovation, sustainability, and optimization.	The study involved collecting employee preferences through questionnaires on CSC management criteria. The responses were organized into three clusters using Principal Component Analysis (PCA).	The study found a ranking of the effectiveness of different digital technologies (CPS, IoT, Cloud Manufacturing, and Big Data Analytics) in facilitating CSC.
Mukherjee et al. (2024)	The paper proposed an Intuitionistic Fuzzy TOPSIS approach for prioritizing supply chain risks.	<ol style="list-style-type: none"> 1. Explored the use of blockchain technologies for risk assessment in supply chain operations, as it was treated as a traceability problem. 2. Investigated the suitability of applying predictive analysis techniques to risk assessment in supply chains. 	Developed a methodology for identifying and prioritizing supply chain risks based on a MCDM model using Intuitionistic Fuzzy TOPSIS to prioritize supply chain risks.	MCDM approach - Combination of Intuitionistic Fuzzy (IF) Set theory and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) - Involves multiple decision-makers (DMs) - Aims to prioritize supply chain risks in a robust and hybrid manner	The proposed Intuitionistic Fuzzy TOPSIS approach for supply chain risk prioritization can improve decision-making and risk management quality within organizations.

3.3. DEMATEL methodology and applications in CSC

DEMATEL is used to analyze and model complex causal relationships among factors in a system, transforming relationships into a cause-effect group. It has been extensively applied in CSC to address various challenges and enhance decision-making processes. One significant application of DEMATEL is in identifying barriers to implementing CSC. Researchers have used DEMATEL to systematically identify and analyze the barriers that hinder the adoption of CSC practices. By mapping out the complex relationships between these barriers, DEMATEL helps decision-makers understand the root causes and develop strategies to overcome them (Ciptomulyono, 2022; Yazdi et al., 2020).

In evaluating the impact of different CSC practices, DEMATEL has proven to be a valuable tool. Researchers have applied DEMATEL to assess the effects of various practices on the overall performance of CSC. This method allows for a comprehensive evaluation of how different practices influence sustainability and efficiency, providing insights into which practices are most beneficial. DEMATEL has also been used to model relationships between factors in CSC. By analyzing the causal relationships among various factors, DEMATEL helps to create a clear picture of how different elements interact within the supply chain. This modeling is crucial for understanding the dynamics of CSC and for identifying key leverage points for improvement. Risk assessment is another area where DEMATEL has been effectively utilized. Researchers have used DEMATEL to identify and evaluate risks in CSC. By mapping out the relationships between different risks, DEMATEL helps companies prioritize their risk management efforts and develop strategies to mitigate the most critical risks (Hu, 2023; Khan et al., 2024).

Finally, DEMATEL has supported strategic decision-making in CSC. By providing a structured framework for analyzing complex relationships and identifying key factors, DEMATEL helps decision-makers choose the most effective strategies for implementing circular economy principles. This strategic support is essential for companies aiming to transition to more sustainable and CSC models (Thakkar, 2021). Table 4 provides an overview of contemporary research on CSC informed by the DEMATEL approach.

3.4. ELECTRE Methodology and Applications in CSC

ELECTRE is a family of multi-criteria decision analysis methods based on the concept of outranking, where alternatives are compared pairwise to determine their relative performance. The Elimination and Choice Expressing Reality (ELECTRE) method has been effectively applied in CSC to address various challenges and enhance decision-making processes. One significant application of ELECTRE is in performance evaluation. Researchers have used ELECTRE to assess the performance of CSC by comparing different performance metrics. This method helps decision-makers identify the most efficient and



sustainable practices, thereby improving the overall performance of the supply chain (Elhidaoui & Kota, 2023; Bizhan & Asia, 2016; Farughi & Mostafayi, 2017).

Table 4 Recent research on CSC based on DEMATEL.

Paper	Remark	Research problem	Research aims	Methodology/ technique	Main finding
Quayson et al. (2023)	The paper uses DEMATEL to evaluate the interrelationships between blockchain-driven dynamic capabilities for developing a CSC.	- How firms can build dynamic capabilities through blockchain to enable a circular economy - The interrelationships between the different dynamic capabilities (sensing, seizing, reconfiguring) required for a CSC - The specific relationships and sequencing of the different dynamic capabilities in the context of a blockchain-driven CSC	- Develop a framework for building blockchain-driven dynamic capabilities to enable a CSC - Evaluate the three major dynamic capabilities (sensing, seizing, and reconfiguring) and their 18 sub-capabilities, as well as the interrelationships between them, using the DEMATEL method - Analyze the mining industry in Ghana as the context for this study	- The Decision Making Trial and Evaluation Laboratory (DEMATEL) method to evaluate three major dynamic capabilities (sensing, seizing, and reconfiguring) and 18 sub-dynamic capabilities related to building blockchain-driven dynamic capabilities for a CSC. The study was conducted in the context of the mining industry in Ghana	- Blockchain-driven sensing, seizing, and reconfiguring dynamic capabilities are crucial for developing a CSC. - These dynamic capabilities do not strictly follow a sequence and instead overlap. - The study identified various cause-effect relationships between these dynamic capabilities, providing insights into their roles.
Bui et al. (2023)	The paper uses DEMATEL to identify the interrelationships among CSC strategy attributes in Industry 4.0 for the canned food industry in Vietnam.	Prior studies have not thoroughly investigated the attributes of CSC strategy (CSCY) in the context of Industry 4.0 (I4.0) using qualitative information. Additionally, the interrelationships between the CSCY attributes in I4.0 have not been well-established.	- Determine the crucial CSC strategy (CSCY) attributes in Industry 4.0 (I4.0) - Investigate the interrelationships among these CSCY attributes in I4.0	The Fuzzy Delphi Method (FDM), Fuzzy Decision-Making Trial and Evaluation Laboratory (FDEMATEL), and Analytical Network Process (ANP) were used in this hybrid method to identify and validate the key CSC strategy (CSCY) attributes in Industry 4.0, as well as to determine the causal relationships between them.	- The study identified 5 key aspects and 25 criteria for CSC strategy in Industry 4.0 through a hybrid method. - The causal group of CSCY attributes includes circular production strategy and technological advancement, while the effect group includes waste circulation, circular product-service system, and circular integration. - The critical criteria for CSCY in I4.0 cover cleaner production, resource efficiency, IoT, robotics, and industrial symbiosis.
Dwivedi et al. (2023a)	The paper identifies and analyzes antecedents of digital supply chains for enabling	- What factors and conditions lead to the implementation of digital supply chains for transitioning toward a circular	The study aimed to identify the antecedents (factors and conditions) that led to the implementation of	The study involved identifying potential antecedents (factors) of digital supply chains	- Advanced information sharing arrangement is a key antecedent of digital supply chains (DSCs) for a circular economy (CE). -



	circular economy using the DEMATEL method.	economy? - There is a lack of research specifically investigating the relationship between digital supply chains and the circular economy paradigm.	digital supply chains (DSCs) for transitioning towards a circular economy (CE).	(DSCs) for the circular economy (CE) The research applied a trapezoidal fuzzy DEMATEL approach to investigate the 19 antecedents.	Effective government policies for DSC and CE implementation are a top antecedent. - Digitalizing the supply chains is a crucial antecedent of DSCs for a CE.
Dwivedi et al. (2023b)	The DEMATEL method is used to analyze factors that sustain circular economy practices in supply chains during a global disruption.	The research gap identified in this paper is the lack of analysis on factors that sustain CE practices in supply chains during a global disruption.	- Identified factors that sustain circular economy (CE) practices during a global disruption - Analyze the identified factors using a mixed-method approach, including a literature review, expert survey, and DEMATEL analysis.	Analyzed the 18 factors using the grey DEMATEL method to determine their priority and cause-effect relationships.	Continued stakeholder pressure, retention of CE and sustainability culture, continued implementation of cleaner technology, feedback system, and ongoing CE training for resilience issues are the top five factors that sustain CE practices during a global disruption.
Chaouni Benabdellah et al. (2023)	The paper identifies and analyzes the key barriers to implementing blockchain technology in viable circular digital supply chains using AHP and DEMATEL methods.	Lack of research on the inconsistent communication among managers and engineers, and the conflicting challenges that prevent the adoption of BT while integrating different dynamic capabilities such as resilience, agility, digitalization, circularity, and sustainability.	Identified the key barriers to blockchain technology (BT) adoption in viable circular digital supply chains (VCDSCs). Examined the causal relationships between these barriers. Determined which barriers were the most prominent, influential, or resulting.	1. Identified barriers to BT adoption in VCDSCs through a literature review. 2. Prioritized the identified barriers using the Analytical Hierarchy Process (AHP) method. 3. Analyzed the causal relationships between the barriers using the DEMATEL method.	The main barriers that have the most impact on other barriers (i.e., the most influential barriers) are "Lack of industry involvement", "Financial constraints", "Missing infrastructure", "Data transparency", "Interoperability" and "Complex protocol". -
Zaman et al. (2023)	The paper uses the DEMATEL method to identify and evaluate factors of digitalization, warehouse management systems (WMS), and supply chain performance.	Intergrate digitalization, warehouse management and performance factors.	Identified the factors of digitalization, WMS, and supply chain performance and evaluate the identified factors using a comprehensive literature review and the grey DEMATEL method	The methodology used in this study was a combination of a comprehensive literature review and the grey DEMATEL method.	- The proposed grey DEMATEL model is highly capable of addressing the digitalization and WMS problem in supply chain networks by considering interdependencies and uncertainties.

In the area of supplier selection, ELECTRE has proven to be a valuable tool. Researchers have applied ELECTRE to select suppliers that meet circular economy criteria. This method allows companies to evaluate and rank suppliers based on multiple sustainability factors, ensuring that the chosen suppliers align with the company’s circular economy goals. This application of ELECTRE helps companies build more sustainable and resilient supply chains (Thakkar, 2021; Lotfi et al., 2023).

ELECTRE has also been employed to prioritize initiatives within CSC. By evaluating various initiatives based on multiple criteria, ELECTRE helps companies identify and focus on the most impactful actions. This prioritization is crucial for effectively implementing circular economy principles and achieving sustainability goals. Risk assessment is another area where ELECTRE



has been effectively utilized. Researchers have used ELECTRE to evaluate and rank risks in CSC. This approach helps companies identify the most critical risks and develop strategies to mitigate them. By providing a structured framework for risk assessment, ELECTRE enhances the resilience and stability of CSC (Kumar et al., 2022; Qu, 2020).

Finally, ELECTRE has supported strategic decision-making in CSC. By providing a clear ranking of alternatives based on their relative performance, ELECTRE helps decision-makers choose the most effective strategies for implementing circular economy principles. This strategic support is essential for companies aiming to transition to more sustainable and CSC models. Table 5 consolidates recent investigations into CSC, employing the ELECTRE method as a framework.

Table 5 Recent research on CSC based on ELECTRE.

Papers	Remark	Research problem	Research aims	Methodology/ technique	Main finding
Gonçalves et al. (2021)	The research paper proposes an ELECTRE TRI method for supplier classification in supply chains, enabling systematic supplier assessment and categorization into cooperation, coordination, and collaboration levels.	Factors related to suppliers are not properly classified	Create Supplier Selection Model for Supply Chains. Categorize suppliers into cooperation, coordination, and collaboration levels.	Quantitative modeling based on ELECTRE TRI method	Supplier Selection Model categorizes suppliers into cooperation, coordination, collaboration levels. Multicriteria Decision Aiding Model classifies suppliers based on performance criteria.
Elhidaoui and Kota (2023)	The research paper utilizes the ELECTRE I method in combination with ANP to analyze barriers and pathways towards a green Agri-food supply chain, focusing on the fish canning industry.	No clear guidelines on the barriers and pathways towards green Agri-food supply chain.	Analyzed Agri-food supply chain barriers.	ANP and ELECTRE I	Cost of greening supply is a relevant barrier. Social and operational pathways are effective.
Kumar et al. (2022)	The paper utilizes the ELECTRE-I approach to estimate best solutions for environmental trade-offs in the cold supply chain, focusing on energy consumption and product life cycle impact.	Environmental trade-off between energy consumption and product life cycle are not clearly identified.	Established environmental trade-off between energy consumption and product life cycle. Identify best-suited alternatives to lower environmental impact in cold chain.	BWM method for best worst analysis. ELECTRE-I approach for environmental trade-off estimation.	Energy consumption' and 'GHG emissions' are critical criteria in CSC. Six alternatives proposed to mitigate environmental impact in cold supply chain.
Farughi and Mostafayi (2017)	The paper combines ANP, ELECTRE, and SIMANP to manage supply chain risks for outsourcing manufacturing. ELECTRE is used as a multi-criteria decision-making	Identifying supply chain risks for outsourcing manufacturing procedures. Developing a hybrid ANP-ELECTRE-SIMANP method for decision-making.	Identify risks in supply chain for outsourcing decisions. Develop a decision-making structure for selecting outsourcing solutions.	ANP, ELECTRE, SIMANP metaheuristic method. Combined ANP-ELECTRE model for decision making.	Identified risks in supply chain for outsourcing decisions. Developed SIMANP metaheuristic method for faster calculations.



	method in the process.				
Bizhan and Asia (2016)	The paper utilizes ELECTRE method to rank factors in green supply chain economics, prioritizing strategies for waste management in Shiraz, favoring domestic production and economic sustainability.	Prioritizing factors affecting green supply chain in waste management. Using economics-based approach with ELECTRE method in Shiraz.	Prioritize factors affecting green supply chain with economics-based approach. Rank strategies for waste management in Shiraz.	ELECTRE method for decision-making	Prioritization of green supply chain factors using economics-based approach. First strategy (s1) recommended for waste management in Shiraz
Solomon et al. (2024)	The paper discusses the integration of circular economy principles into global supply chain strategies.	Developed new business models to advance circular economy practices in supply chains	Investigated the core principles of the circular economy and understand their potential impact on global supply chains.	Comparisons of various methods	The transition from a linear to a circular economy model is driving a paradigm shift in SCM. Key CE principles are being integrated into supply chain strategies.

3.5. ANP methodology and applications in CSC

The Analytic Network Process (ANP) has been effectively utilized across various studies to address the complexities of CSC, each contributing unique insights while also intersecting in their methodologies and findings. Kumar et al. (2021) and Dwivedi et al. (2023) both focused on identifying and analyzing barriers and antecedents in adopting circular economy practices, albeit in different contexts—agriculture and digital supply chains, respectively. Kumar et al. (2021) used ISM-ANP to reveal the hierarchical structure and interdependencies of barriers in the agriculture supply chain, while Dwivedi et al. (2023) applied ANP to prioritize factors such as technology, policy, and organizational elements in digital supply chains.

Yontar (2023) and Tseng et al. (2022) also employed ANP but in the context of evaluating critical success factors and collaboration influences. Yontar (2023) focused on blockchain technology in the agri-food supply chain, using ANP to prioritize success factors crucial for its adoption within a circular economy framework. This aligns with Tseng et al. (2022), who used ANP to assess the influence of vision and learning on collaboration within the healthcare CSC in Vietnam, identifying key areas for improvement.

The significance of these studies lies in their collective ability to provide a comprehensive understanding of the factors influencing CSC. Kumar et al. (2021) and Dwivedi et al. (2023) offer insights into overcoming barriers and prioritizing antecedents, which are crucial for policymakers and practitioners aiming to implement circular economy practices. Meanwhile, Yontar (2023) and Tseng et al. (2022) highlight the importance of critical success factors and collaboration, respectively, offering valuable strategies for enhancing supply chain practices in their respective sectors. ANP enables informed decision-making by addressing barriers, evaluating success factors, and assessing collaboration influences, ultimately promoting sustainability across various sectors. This holistic approach underscores the interconnected nature of supply chain challenges and the need for comprehensive strategies to achieve circularity (Gonzalez-Urango et al., 2024; Moslem et al., 2023; Petrillo & Karpak, 2021). Table 6 presents a summary of recent research on CSC utilizing the ANP method.

Table 6 Recent research on CSC based on ANP.

Paper	Remark	Research gaps	Study objectives	Methodology	Main findings
Agnusdei et al. (2023)	The paper uses SWOT-ANP-ADAM to evaluate how digitalization can drive circularity in the agroindustry.	Not mentioned (the abstract does not suggest any research gaps)	- To investigate the role of digitalization in serving as a driver to achieve circularity in the agroindustry - To evaluate critical factors (CFs) through	The methodology used in this study involved a SWOT analysis to identify internal and external factors related to digitalization and circularity in the	- Digitalization plays a crucial role in boosting circularity in the agroindustry. - The most impactful strategies for transitioning to a circular economy in the



			the Analytical Network Process (ANP) - To rank strategic alternatives using the Axial-Distance-Based Aggregated Measurement (ADAM) method to inform management decisions.	agroindustry, an Analytical Network Process (ANP) to evaluate the critical factors, and an Axial-Distance-Based Aggregated Measurement (ADAM) method to rank the strategic alternatives for improving circularity.	agroindustry are linking sustainability performance to incentives and increasing consumer inclusion and awareness. - The study provides recommendations to help managers and practitioners adopt strategies to make the agroindustry more circular and sustainable.
Gonzalez-Urango et al. (2024)	This paper reviews the use of Analytic Network Process (ANP) in economics, finance and management, but does not specifically address its use for CSC.	The study involved understanding the use of the Analytic Network Process (ANP) as a standalone method versus in combination with other methods. It explored the application of ANP in practical scenarios beyond sustainable projects.	The study explored the recent use of the Analytic Network Process (ANP) in decision-making processes within the areas of economics, finance, and management. It identified common contingency factors, current trends, and representative studies, as well as directions for further research applications in the target areas.	- Systematic literature review of 434 ANP studies from 2012-2021 in the Scopus database, focusing on the areas of business, management, accounting, economics, econometrics, and finance - Citation-based graph and contingency analysis to identify usage trends - Highlighting of representative studies in each area	- The most common applications of the Analytic Network Process (ANP) are in sustainable SCM and business evaluation frameworks. - There is a trend of using ANP in applications that engage stakeholders in the decision-making process. - ANP is most commonly used as part of a multi-method or integrated decision-making approach, rather than as a standalone method.
Rahardjo et al. (2023)	A hybrid DANP-VIKOR model is used to select the best sustainable supplier in the electronics industry, considering interdependent criteria.	The authors mention some limitations of the study, such as the limited scope of the survey and the potential to include additional criteria.	1. Rank and select the best sustainable supplier using a hybrid MCDM model 2. Analyze and improve the gaps in each dimension and criterion using influential network relationship maps 3. Illustrate the hybrid MCDM model for sustainable supplier selection and improvement using an empirical case study in the display manufacturing industry in Taiwan.	- Used the DEMATEL method to understand the interrelationships among the dimensions and criteria for sustainable supplier selection - Apply the DANP method to determine the influential weights of the criteria - Employ the VIKOR method to rank the alternatives, identify the best sustainable supplier, and assess the performance gaps to provide improvement suggestions.	- The three dimensions of sustainability (economic, environmental, and social) are interdependent, with the economic dimension influencing the environmental and social dimensions. - The hybrid MCDM model using DANP and VIKOR identified supplier S3 as the best sustainable supplier among the three alternatives.
Moslem et al. (2023)	This paper compares the use of Analytical Network Process	No research gaps suggested. The paper does not explicitly identify	1. Assess the quality of public bus transport supply in Budapest 2. Identify	- Comparative analysis of the Analytical Hierarchy Process (AHP) and Analytical Network	- The AHP analysis found that "Service Quality" was the most critical issue to be developed for



	(ANP) and Analytical Hierarchy Process (AHP) for assessing public transport supply quality, but does not address CSC.	any research gaps, but it does suggest some potential areas for further research as outlined above.	the most effective improvements to increase passenger satisfaction and attract new users 3. Compare two MCDM methods (AHP and ANP) for evaluating public bus transport supply quality	Process (ANP) methods for evaluating public bus transport supply quality - AHP was used to analyze the hierarchical structure of 24 criteria across 3 levels - ANP was used to consider the interrelationships and feedback between the 24 criteria, requiring 276 pairwise comparisons.	the public bus transport system in Budapest. - The ANP analysis highlighted "Tractability" as the most significant issue to be developed, followed by "Service Quality", "Transport Quality", "Information before travel" and "Perspicuity". - The top three most significant criteria identified by both the AHP and ANP analyses were "Service Quality", "Transport Quality" and "Tractability".
Gholian-Jouybari et al. (2023)	The paper proposes a closed-loop agri-food supply chain network design for the soybean industry using a mixed-integer linear programming model and multi-objective optimization.	Not mentioned (the abstract does not suggest any specific research gaps or unanswered questions that the paper aims to address)	The study developed a novel mathematical model for a closed-loop agri-food supply chain network in the soybean industry, considering sustainability and circular economy principles. It optimized the network to maximize profit, minimize CO2 emissions, and satisfy customer demand.	- Formulation of a mixed-integer linear programming model for a closed-loop agri-food supply chain network design for the soybean industry - The model has multiple objectives: maximizing total net profit, minimizing CO2 emissions, and maximizing customer satisfaction	A novel mixed-integer linear programming model was developed to design a closed-loop agri-food supply chain network for the soybean industry, considering sustainability and circular economy principles. Four multi-objective optimizers and three hybrid algorithms were utilized to solve the NP-hard nature of the network, with MOGWO being better suited for small-size problems and MOHSA being highly effective for medium and large-size problems.
Foroozesh et al. (2023)	A hybrid decision-making method using robust programming and interval-valued fuzzy sets for sustainable-resilient supply chain network design considering circular economy and technology levels.	Not mentioned (the abstract does not explicitly mention any research gaps that the paper aims to address)	- Developed a three-stage optimization approach for sustainable-resilient supply chain network design for perishable products - Consider product lifetime, financial resources, and technology levels in the optimization model - Incorporate suppliers' green image and circular economy rating in the supply chain network	A three-stage optimization approach with a circular economy perspective for sustainable-resilient supply chain network design for perishable products - Determining suppliers' green image and circular economy rating using a new interval-valued fuzzy (IVF)-compromise decision-making method based on possibilistic mean and standard deviation evaluations.	- The study introduces a new three-stage optimization approach with a circular economy perspective for sustainable-resilient supply chain network design for perishable products. - The proposed model specifies the number of facilities and the number of products flowing within the supply chain in case of disruption. - The study incorporates suppliers' green image and circular economy rating in the



Romagnoli et al. (2023)	Sustainable practices and digital technologies like TMS, IoT, ML, and 3D printing can enhance CSC management.	Identifying a comprehensive portfolio of sustainable practices that can enable CSC implementation. Examining the impact of digital technologies on CSC across different industries	Investigate how firms can enhance CSC functionality through sustainable practices and digital technologies. Analyze the benefits of investing in specific technologies to boost the impact of technologies and sustainable practices on CSC	Survey data collection from a sample of 157 supply chain experts - Pre-testing and refinement of the survey instrument based on expert feedback - Use of partial least squares path modeling (PLS-PM) as the primary data analysis technique	supply chain network structure. The adoption of sustainable practices is more effective than digital technologies in enabling CSC management. Besides, the adoption of specific digital technologies, such as TMS, IoT, ML, and 3D printing, can enhance the positive effects of sustainable practices and digital technologies on CSC management and business performance.
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4. Publication Trend

To understand the growing interest in MCDM within supply chain management (SCM), it is helpful to look at the publication trends over the years. The graph illustrated in Figure 3 shows the number of research papers published based on search done on “multi-criteria decision making in supply chain” on Scopus web portal from 2000 to 2024 shows a clear upward trend. Initially, from 2000 to 2003, the topic was in its early stage with very few publications. The period from 2004 to 2007 saw a noticeable increase, reflecting growing academic interest. A significant surge occurred between 2008 and 2014, likely due to the increasing complexity of supply chains and the impact of the global financial crisis. From 2015 to 2019, the field matured with a steady rise in publications, peaking at 174 in 2018. The recent surge from 2020 to 2024, reaching a peak of 286 in 2023, can be attributed to technological advancements, global disruptions like the COVID-19 pandemic, and a heightened focus on sustainability and resilience.

The broader scope of the search, which focused on general supply chain MCDM, was intentional because the principles of MCDM are applicable to both traditional supply chain and CSC. MCDM frameworks are designed to handle complex decision-making processes involving multiple conflicting criteria, which are common to all types of supply chains. By exploring MCDM in the context of a general supply chain, we can leverage well-established insights and methodologies that are equally relevant to CSC. These insights can then be adapted to address specific CSC challenges, such as resource regeneration, waste reduction, and sustainability. Therefore, a broader search provides a more comprehensive understanding of decision-making approaches that can be refined for circular supply chain applications.

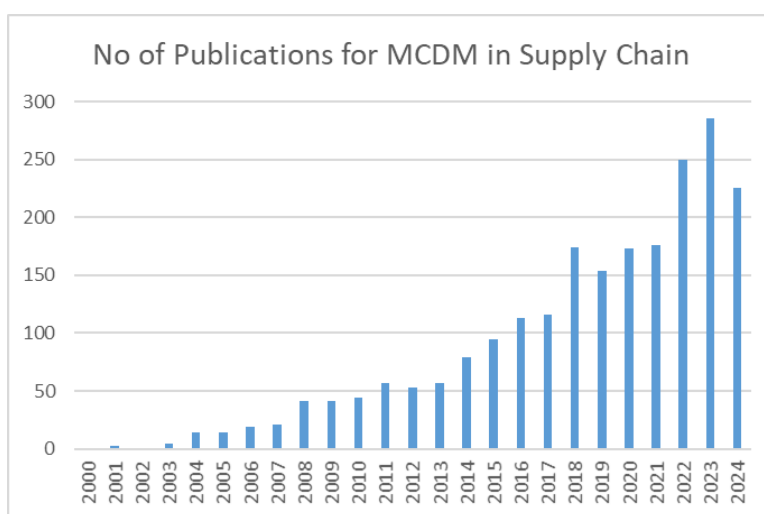


Figure 3 Number of publications in MCDM in Supply Chain from 2000 to 2024. (Data from Scopus document search within: Article title, Abstract, Keywords; Search documents: multi AND criteria AND decision AND making AND supply AND chain). *Source:* Scopus Database.

Overall, the trend highlights the growing importance of multi-criteria decision-making in SCM, driven by the need for more effective, efficient, and resilient strategies. With ongoing technological advancements and an increasing understanding



of the behavior of CSC, the future of research in MCDM for CSC looks very promising. The data on publications related to “multi-criteria decision making in supply chain” across various subject areas reveals significant trends as illustrated in Figure 4. Engineering leads with 1,055 papers, reflecting the field’s focus on optimizing complex systems and processes, which is central to SCM. Computer Science follows with 860 papers, highlighting the role of computational methods and algorithms in decision-making. Business, Management, and Accounting (705 papers) and Decision Sciences (505 papers) also show high numbers, as these areas are directly concerned with strategic and operational decision-making in supply chains. Mathematics (358 papers) contributes through the development of models and quantitative methods essential for MCDM. Environmental Science (342 papers) and Energy (246 papers) have substantial contributions due to the increasing emphasis on sustainable and energy-efficient supply chains. Social Sciences (235 papers) and Economics, Econometrics, and Finance (144 papers) reflect the growing interest in the socio-economic impacts and financial aspects of supply chain decisions. Chemical Engineering (91 papers) and other areas (348 papers) indicate the interdisciplinary nature of MCDM applications in supply chains. The high numbers in these areas are justified by the critical need for effective decision-making tools to address the complexities and challenges in modern supply chains.

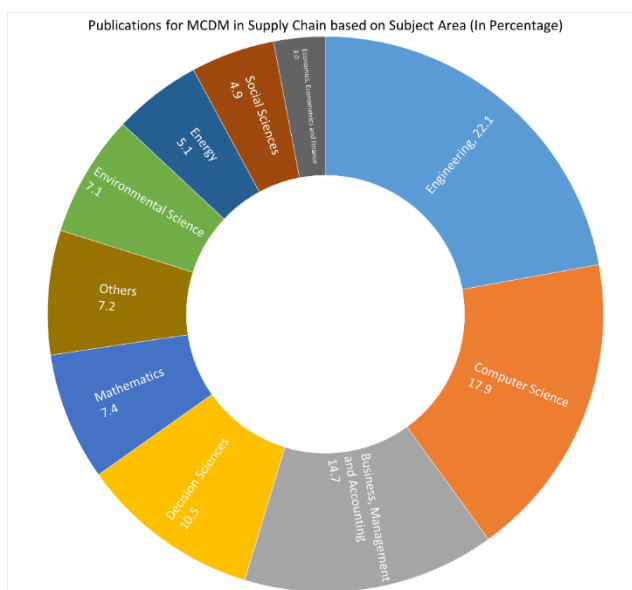


Figure 4 Publications for MCDM in Supply Chain based on subject area (in percentage). Source: Scopus Database.

The data on publications related to “multi-criteria decision making in supply chain” across different sources reveals remarkable statistics as depicted in Figure 5. Journals are the predominant medium, with 1,682 papers, reflecting the rigorous peer-review process and wide accessibility that journals offer, making them the preferred choice for disseminating new research. Conference proceedings, with 333 papers, indicate the importance of presenting and discussing recent findings in academic and professional gatherings, which often lead to further research and collaboration. Book series (155 papers) and books (41 papers) contribute to the field by providing comprehensive and in-depth analyses, often serving as key references for both academic and practical applications. This distribution highlights the diverse channels through which research in this area is shared, with journals leading due to their credibility and reach, while conferences and books play crucial roles in fostering discussion and providing detailed insights.

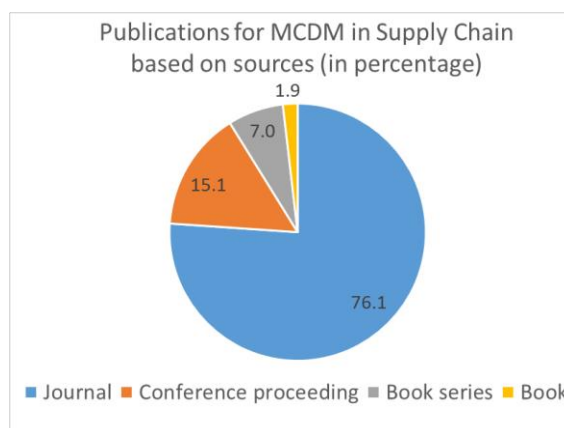


Figure 5 Publications for MCDM in Supply Chain based on subject area (in percentage). Source: Scopus Database.



As depicted in Figure 6, in term of the journals, the publications have been made in a total of 164 sources (journal/ conference proceeding/ book series/ book). At the forefront, both Sustainability and the Journal of Cleaner Production lead with 74 papers each, showcasing their pivotal role in advancing research that intersects sustainability and decision-making in supply chains. These journals are likely to feature studies that explore how MCDM can help organizations balance environmental concerns with economic and operational goals, providing frameworks for implementing sustainable practices across supply chains.

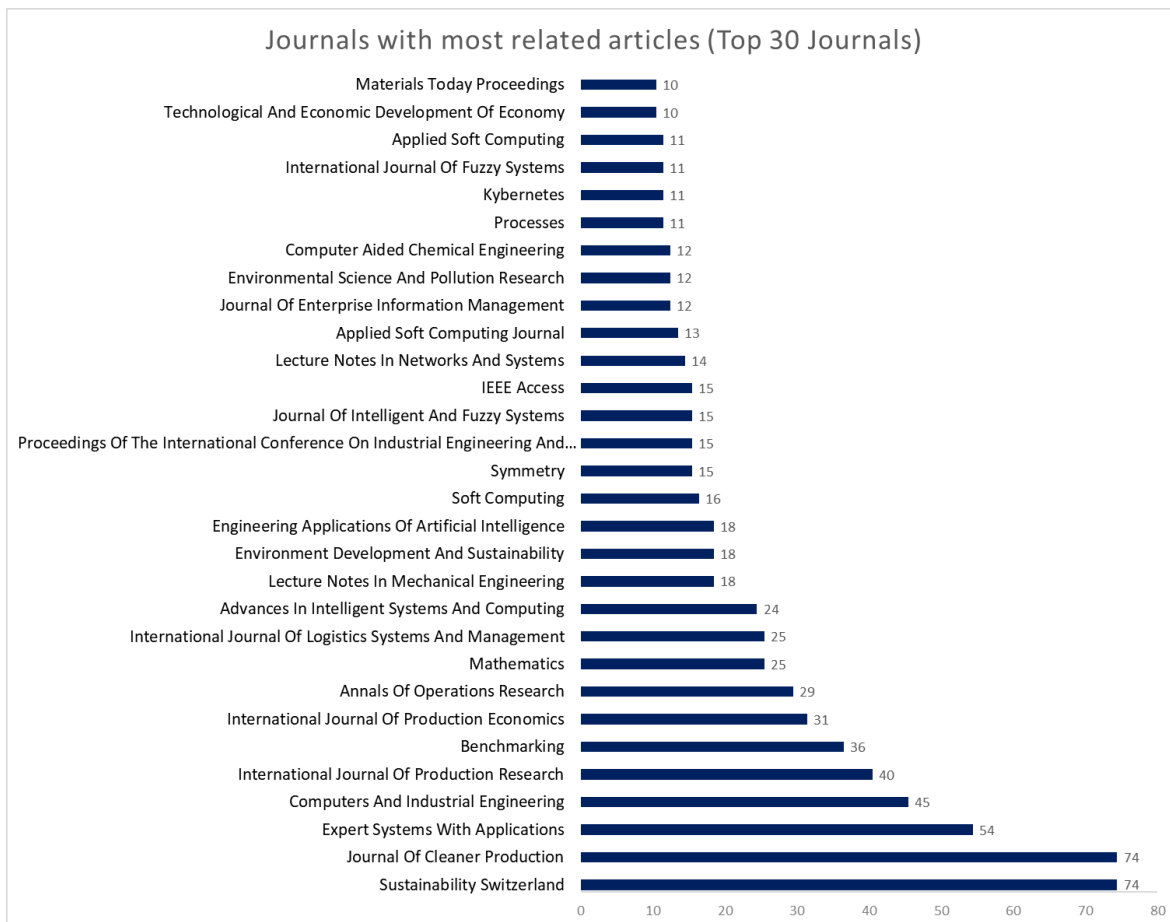


Figure 6 Distribution of related articles in top 30 journals. Source: Scopus Database.

Following these, Expert Systems with Applications (54 papers) and Computers and Industrial Engineering (45 papers) illustrate the critical role of technology in enhancing decision-making processes. These journals typically publish research on intelligent systems and computational models, which are essential for optimizing complex supply chain decisions. The integration of MCDM with advanced analytics can empower organizations to evaluate multiple conflicting criteria—such as cost, efficiency, and sustainability—leading to more informed and effective decisions.

The International Journal of Production Research (40 papers) adds another layer, focusing on foundational research in production processes. This journal's contributions are crucial for understanding how MCDM techniques can be applied to improve production efficiency and sustainability, essential elements in today's supply chains. The rest of the journals, while having lower citation counts, still play a vital role in the discourse around MCDM in supply chains. They cover diverse topics such as logistics, operations research, and engineering applications, reflecting a wide array of methodologies and perspectives on decision-making. These publications underscore the importance of examining various aspects of supply chains, including logistics systems and mathematical modeling, which are key to developing robust MCDM frameworks.

Overall, the data indicates a vibrant research landscape that prioritizes sustainability and technological innovation in supply chain decision-making. The strong focus on these areas suggests that researchers are increasingly looking for ways to navigate the complexities of SCM in a manner that meets both operational goals and sustainability objectives.

5. Challenges and opportunities in MCDM for CSC

The challenges in MCDM for CSC are multifaceted. One significant challenge is the complex interdependencies among various factors, which can be difficult to model and analyze accurately. Methods like DEMATEL (Decision Making Trial and Evaluation Laboratory) are particularly useful here as they help visualize and understand the cause-effect relationships among



factors. Another challenge is the availability and quality of data. Reliable and comprehensive data is crucial for effective MCDM, but obtaining high-quality data across the entire supply chain can be difficult, especially in sectors with less digitalization. Additionally, the dynamic nature of supply chains, with constantly changing variables and conditions, requires MCDM methods to be adaptable and capable of handling real-time data. Engaging multiple stakeholders with varying priorities and perspectives adds another layer of complexity to the decision-making process. Methods like AHP can help in structuring these diverse inputs into a coherent decision-making framework.

Despite these challenges, there are significant opportunities in using MCDM for CSC. Enhanced decision-making is one of the primary benefits, as MCDM methods like AHP, TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution), and DEMATEL provide structured frameworks for evaluating multiple criteria, leading to more informed and balanced decisions. Improved sustainability is another opportunity, as MCDM can help organizations make decisions that support environmental, social, and economic goals. For example, AHP can be used to prioritize sustainability criteria in supplier selection. MCDM methods also aid in risk management by identifying and mitigating risks in CSC. TOPSIS, for instance, can rank alternatives based on their closeness to an ideal solution, helping to identify the most robust options under uncertain conditions. Furthermore, using methods like AHP and DEMATEL can facilitate better communication and alignment among stakeholders by providing a clear and transparent decision-making process.

In detail, AHP is used to break down complex decision-making problems into a hierarchy of simpler sub-problems, with stakeholders comparing elements pairwise to establish priorities. These comparisons are then used to calculate a weighted score for each decision alternative. However, AHP can be time-consuming and may suffer from subjective biases in pairwise comparisons. TOPSIS, on the other hand, ranks alternatives based on their distance from an ideal solution and a nadir solution, evaluating alternatives against each criterion and calculating the Euclidean distance from the ideal and nadir solutions. The alternative closest to the ideal solution and farthest from the nadir solution is preferred, though TOPSIS requires precise data and may not handle qualitative criteria well. DEMATEL is used to understand and visualize the cause-effect relationships among factors in complex systems, with stakeholders evaluating the direct influence of each factor on others to construct a cause-effect diagram. However, DEMATEL can be complex to implement and interpret, especially in highly interconnected systems.

In conclusion, MCDM methods like AHP, TOPSIS, and DEMATEL offer significant opportunities for enhancing decision-making in CSC by providing structured frameworks to evaluate multiple criteria. However, challenges such as data quality, dynamic supply chain conditions, and stakeholder involvement need to be addressed to fully leverage these methods. By overcoming these challenges, organizations can make more informed, sustainable, and resilient decisions in their CSC management.

6. Conclusions

In conclusion, the integration of multi-criteria decision-making (MCDM) methodologies within CSC represents a pivotal advancement towards achieving sustainability and resource efficiency. As organizations navigate the complexities of CSC, the ability to evaluate multiple criteria simultaneously allows for informed decision-making that balances economic, environmental, and social considerations. The applications of MCDM methods such as AHP, TOPSIS, DEMATEL, ELECTRE, and ANP showcase their versatility in addressing various challenges—from supplier selection and performance evaluation to risk management and identifying barriers to implementation.

The growing body of research indicates a robust interest in these methodologies, underscoring their importance in optimizing CSC. The upward trend in publications reflects a shift towards a deeper understanding of how these decision-making tools can facilitate the transition to sustainable practices. Moreover, as industries increasingly adopt circular economy principles, leveraging advanced technologies alongside MCDM approaches will further enhance transparency, efficiency, and collaboration among stakeholders.

Ultimately, the ongoing exploration and refinement of MCDM methodologies within CSC hold significant promise for fostering a more sustainable and resilient economy. As businesses strive to minimize waste and maximize resource utilization, these decision-making frameworks will be essential in guiding strategies that align with both corporate goals and broader environmental objectives. The future of SCM lies in embracing these methodologies, paving the way for a circular economy that benefits not only businesses but also society and the planet as a whole.

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Ethical Considerations

Not applicable.

Conflict of Interest

The authors declare no conflicts of interest.

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