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Machine learning technology and the circularity of supply chains: A systematic literature review

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INTRODUCTION

Review question / Objective “How does ML technology improve the performance of SCs toward circularity?”

Background Circular supply chains (CSCs) draw more interest from scholars and practitioners due to environmental and resource issues. CSCs generate value by extending the life cycles of products, compo-nents, and materials through coordinated forward and reverse SCs. The primary objectives of CSCs are to close resource loops through recycling or remanu-facturing, increase resource efficiency by using fewer resources throughout the product life-cycle, and extend product lifetimes through design changes or repairs. Furthermore, CSC encompasses reverse logistics and closed-loop SCs (CLSCs). However, CSCs are conceptually different from CLSCs. CLSCs involve returning used products to the same producer within the same SC for recycling, reuse, or remanufacturing, whereas CSCs consider more broadly the return of materials to the original SC sector (closed-loop), other sections of the same SC (open-loop), or even to other SCs (open-loop).

To move forward to CSCs, significant modifications are needed across all stages of SCs. One type of such modification is the introduction of machine learning (ML) algorithms to SCs with the objective of facilitating the transition to circularity. For instance, Kazancoglu et al. determine ML and data mining as the most efficient big data solutions for circu-larity transition in dairy SC. Moreover, in recent years, there has been growing interest in the application of ML techniques in the context of circular economy (CE) and sus-tainable SCs. Several literature reviews have focused on the potential of ML and artifi-cial intelligence (AI) to enhance sustainability and circularity in various industries, in-cluding construction, transportation, healthcare, and manufacturing. These reviews have established the importance of digitalization in CE research, but they do not specifically explore the use of ML technology and their algorithms in SCs for ad-vancing circularity strategies.

To address this research gap, our study takes a unique perspective by focusing specifically on the application of ML techniques in different stages of CE-based SCs. To structure our analysis, we adopt a comprehensive framework that covers the entire SC, from sourcing to waste management. Our objective is to perform a content analysis of existing literature using this framework and developing some research propositions to identify specific areas where ML can be applied throughout the CSC to effectively im-plement circularity strategies in SCs. By providing a detailed analysis of ML techniques in the context of CSCs and de-veloping some research propositions, our study contributes to the existing literature by offering insights into the potential of ML to improve circularity in SCs. We intend to answer the research question: "How does ML technology improve the performance of SCs toward circularity?" Through synthesizing the current state of the art in the application of ML in CSCs, we develop research propositions, identify future research paths, detect CSCs and industries applying ML techniques, and determine executable ML methods for different sections of several CSCs and industries.

Rationale Despite its potential, the application of ML in CSCs is still underexplored, and there is a need for a comprehensive understanding of how ML can be leveraged to overcome the barriers to circularity. This review is driven by the need to systematically examine the current state of research on the integration of ML in CSCs, identify the key challenges and opportunities, and provide insights into best practices and future research directions.

By synthesizing existing literature, this review aims to demonstrate the value of ML in enhancing circular supply chains and to provide actionable knowledge that can help businesses, policymakers, and researchers drive the adoption of ML technologies in pursuit of a circular economy. This systematic examination will contribute to the field by highlighting the role of ML in facilitating the transition towards sustainable and circular supply chain practices, ultimately supporting broader environmental and economic goals.

METHODS

Strategy of data synthesis We employ systematic literature review process to ensure a transparent, scientific, and replicable approach. We use the Scopus database to search for articles. The papers indexed in Scopus are selected through strict criteria, making them reliable sources for academic research. Additionally, to provide a comprehensive overview and mitigate the risk of omitting relevant studies, we expanded our search to include the Web of Science (WOS) database. These databases are known for their robust repositories of peer-reviewed literature across multiple disciplines.

Our search strategy was meticulously designed to capture the intersection of ML and CSCs. We employed a set of targeted keywords, including "machine learning," "artificial intelligence," "circular supply chain," "circular economy," "closed-loop sup-ply chain," "circularity," "reverse supply chain," and "reverse logistics." These terms were used in combination with Boolean operators (AND/OR) to ensure that all relevant studies were identified. The search was applied to the titles, abstracts, and keywords sections of articles. We limited the search to specific document types, including "Arti-cles," "Articles in press," "Review articles," "Conference papers," and "Conference re-views," all published in peer-reviewed journals and conference proceedings. Non-English language publications were excluded to maintain consistency and acces-sibility.

Furthermore, our inclusion criteria were refined to focus on studies that explicitly addressed the circularity of SCs, excluding those that dealt solely with linear SCs without any elements of circularity. Additionally, we excluded articles where ML was not a central theme, ensuring that our review remained focused on the application of ML within circular SCs. This targeted approach was crucial in narrowing down the vast amount of literature to a manageable and relevant set of studies.

Eligibility criteria Concept: The review specifically targeted studies that examined the application of machine learning (ML) technologies within the context of CSCs. Eligible studies had to explicitly address how ML contributes to enhancing circularity, optimizing supply chain processes, or overcoming barriers in the implementation of circular economy principles. Articles that did not focus on both ML and circular supply chains were excluded.

Context: The review included studies conducted in diverse geographical contexts and across various industries where CSC principles are applied. The context also covered different stages of the supply chain, including product design, manufacturing, distribution, and end-of-life processes, provided they involved elements of circularity facilitated by ML. Studies focusing solely on linear supply chains or unrelated to the circular economy were excluded from the review.

These criteria ensured that the selected studies were relevant and provided valuable insights into the role of ML in enhancing the circularity of supply chains.

Source of evidence screening and selection The screening and selection process for this scoping review involved a multi-stage approach to ensure the inclusion of relevant and high-quality studies.
Stage 1: Initial Screening
The first stage involved an initial screening of titles, abstracts, and keywords of articles identified through the Scopus and Web of Science (WOS) databases. This initial screening aimed to filter out studies that clearly did not meet the inclusion criteria, focusing on articles that mentioned both machine learning (ML) and circular supply chains (CSCs). Any studies that did not address these core topics were excluded at this stage.
Stage 2: Full-Text Review
The second stage involved a detailed review of the full texts of the remaining articles. During this phase, each article was assessed against the predefined eligibility criteria, which included a focus on the application of ML in CSCs, publication in peer-reviewed journals or conferences, and relevance to the specified context of circular supply chain processes. Articles that lacked sufficient detail on ML applications, focused solely on linear supply chains, or were not in English were excluded.
Procedures for Resolving Disagreements
To ensure consistency and objectivity, two independent reviewers conducted the screening and selection process. In cases where there were disagreements between reviewers regarding the eligibility of a study, a third reviewer was consulted to provide an additional perspective. Discrepancies were resolved through discussion and consensus, ensuring that all included studies met the criteria and were relevant to the review's objectives.
This structured approach helped to systematically identify, screen, and select the most relevant sources of evidence, providing a robust foundation for the scoping review.

Data management Data for this review were managed using Microsoft Excel, which was used to store, organize, and code information from the included studies. Excel facilitated the systematic extraction and categorization of key data points, such as study characteristics, machine learning techniques, circular supply chain stages, and relevant findings. The spreadsheet was designed with specific columns for each variable of interest to ensure consistency and ease of analysis.
Data coding was conducted directly within Excel, allowing for efficient sorting, filtering, and analysis of the data to identify patterns and trends. The Excel file was regularly updated and backed up to secure storage to prevent data loss, and access was limited to the research team to maintain data integrity and confidentiality throughout the review process.

Language restriction Yes, language limits were imposed on the search. The review included only articles published in English to ensure accessibility and consistency in the analysis.

Country(ies) involved Finland.

Keywords circular supply chain; circular economy; machine learning; artificial intelligence; systematic literature review.

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