TECHNOLOGICAL ASPECTS IN CIRCULAR SUPPLY CHAIN MANAGEMENT

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Abstract - Shifting from a linear make-use-dispose financial model to a higher sustainable circular economy requires companies to embrace circular supply chain management practices. Nonetheless, navigating this transition poses a fundamental challenge of tracing material reuse throughout various life cycles involving various stakeholders. Blockchain technology presents a promising solution to address the complexities of circular supply chain management. This study outlines a framework architecture for blockchain-enabled circular supply chain management in the fast fashion industry. The suggested framework structure underwent validation by two experts specializing in blockchain technology and supply chain management. Discussions on regulatory implications are conducted to guide the implementation of blockchain technology in advancing the circular economy agenda.

Index Terms - Supply Chain, CSCM, Circular Economy, Blockchain Technology

1 INTRODUCTION

Industrial activities contribute significantly to global environmental degradation and the depletion of resources. Over the past decade, the concept of the circular economy (CE) has emerged to address these challenges. The definition of CE varies as each stakeholder interprets it differently. For instance, Kirchherr et al. (2017) developed an inclusive concept of CE by synthesizing more than hundred relevant definitions, describing CE as:

A monetary framework substitutes the concept of 'end-of-life' with strategies focused on minimizing, reusing, recycling, and recovering materials throughout production, distribution, and consumption processes. This framework operates at various levels—micro (products, companies, consumers), meso (eco-industrial parks), and macro (city, region, nation, etc.)—with the goal of achieving sustainable development. It aims to simultaneously foster environmental resilience, economic prosperity, and social equity, benefiting both current and future generations.

At the outset, the linear model prioritizes resource efficiency, while the circular economy places greater emphasis on resource eco-effectiveness. Moreover, in the linear model, discarded items may be downcycled to create something of lesser value than the original, whereas in the CE, there is a focus on upcycling discarded items to produce something of higher value. The recovery and utilization of waste can enhance the competitiveness of an organization by improving resource efficiency, reducing overall costs, enhancing the organization's reputation, and reducing environmental burdens.

When every participant in the supply chain effectively collaborates to embed the concept of Circular Economy into every stage of the supply chain process, they have the potential to create innovative business models and enhance supply chain capabilities. This collaboration can lead to the goal of achieving zero waste by repurposing all applicable resources throughout the entire life cycle of the supply chain. This concept is recognized as circular supply chain management (CSCM), which aims to put Circular Economy (CE) principles into action at a granular level. The implementation of CSCM presents hurdles in efficiently tracking the upcycling of materials across numerous life cycles involving various supply chain collaborators. Challenges typically arise from factors such as cultural and societal norms, informal regulations and policies, technology limitations, data and skill deficiencies, the complexity of circular economic systems, and market dynamics.

Numerous strategies have been investigated and put into practice to tackle these encounters. Between these strategies, Blockchain technology (BCT) have gained considerable traction for two main reasons. Initially, this technology has revealed remarkable progress in bolstering supply chain traceability, sustainability, and data security in recent years. Moreover, BCT offers the potential to address multiple Circular Economy (CE) challenges concurrently.

Numerous recent studies have crafted frameworks to provide direction for implementing BCT in evaluating how the product life cycle can improve environmental performance. However, there is a scarcity of research focused on investigating the application of blockchain to facilitate Circular Supply Chain Management (CSCM) within specific industries. While the life cycle assessment method is firmly established, CSCM remains an emerging concept that necessitates further exploration. Moreover, there exists a gap in understanding the potential impact of blockchain-enabled CSCM on regulatory and policy decision-making to drive progress in the CE.

This study concentrates on the fast fashion sector and seeks to accomplish the following objectives:

- To formulate a framework structure for implementing blockchain-enabled Circular Supply Chain Management within the fast fashion industry.
- To investigate the theoretical and regulatory implications associated with the adoption of blockchain technology to advance CSCM practices.

The primary aim of Circular Economy and Circular Supply Chain Management is to achieve zero waste. Given the fast fashion industry's widely recognized shortcomings in environmental sustainability, this study focuses on it as an ideal setting to explore the integration of blockchain-enabled CSCM.

2 TECHNOLOGY IN CSCM

2.1 Blockchain technology

Nakamoto first introduced the concept of Blockchain Technology in 2009. He described it as a technology that utilizes data mining and Bitcoin techniques to establish a data structure and encrypt the exchange of data. The data stored within a blockchain is permanently kept online, ensuring high transparency and security. The fundamental features of Blockchain Technology (BCT) encompass decentralization, immutability, transparency, traceability, tamper-proof transactions, anonymity, and authenticity. It is contended that BCT holds applicability across diverse domains, transcending its association solely with cryptocurrency and capital markets. Moreover, it offers comprehensive instructions on smart contracts, network security and privacy, as well as various applications and platforms. Particularly, with the progression of the IoT, the integration of Blockchain Technology can assist organizations in fostering collaborative services. Likewise, the service architecture has been enhanced owing to the swift evolution of BCT. Beyond its conventional business and service applications, Blockchain Technology has also facilitated the shift towards a circular economy.

2.2 Blockchain technology and circular economy

Although the transition to a Circular Economy signifies a trend within the fashion industry and its supply chain, there exist several obstacles impeding this shift:

- Absence of standardized approach
- Escalating complexity resulting in resistance to altering traditional linear economy and industry models
- Intellectual property protection concerns
- Elevated costs
- Lack of price assurance for recycled materials and reused products
- Limited consumer awareness of Circular Economy

Experts and the academic community have employed various approaches to address these obstacles. Blockchain Technology (BCT) offers effective support for the progress towards CE. Firstly, BCT can facilitate the integration and sharing of information across the entire supply chain process. As a result, the exchange of materials and products can take place seamlessly. Furthermore, Blockchain Technology (BCT) offers heightened security for storing and managing data online, preventing the leakage of sensitive information and safeguarding organizational intellectual property. Ultimately, all participants in the supply chain, especially consumers, can swiftly access more information upstream, including details related to design, raw materials, and manufacturing processes. BCT has the potential to enhance consumer comprehension of the entire supply chain, thereby fostering improved integration and collaboration among supply chain participants.

2.3 Blockchain technology for conventional supply chains

The following strategies has the potential to effectively aid in achieving the BT and SCM:

- Cost - Blockchain Technology can produce a unique code for each transaction, enabling complete verification of the financial flow throughout the entire supply chain process.
- Speed - Blockchain Technology can expedite processes by reducing physical interactions and communications.
- Risk control - Through Blockchain Technology, transactions can only proceed when all involved parties reach consensus at predetermined touchpoints within the blockchain network. This functionality effectively mitigates the risk of data manipulation in all supply chain transactions.
- Sustainability - Blockchain Technology can assist in establishing quantifiable and meaningful performance metrics for environmental, economic, and social sustainability.
- Adaptability - Blockchain Technology empowers buyers to track and trace their orders from upstream to downstream, facilitating easy adjustments by buyers and swift adaptation by suppliers to changes.

Before exploring studies on the application of Blockchain Technology in circular supply chains within the fast fashion industry, this paper establishes context regarding the industry's imperative to transition to a circular economy and elucidates how Blockchain Technology can be advantageous in this context.

2.4 The style business, circular economy, and blockchain technology

The fashion industry generates over $450 billion in global sales, making it one of the leading sectors worldwide. However, it has also been identified as one of the most destructive companies for the environment and has faced ongoing pressure to transition to a high circular economic model.

Throughout the entire lifecycle, from initial design and manufacturing to final service stages, Circular Economy principles drive the fashion industry to prioritize sustainability. This entails a focus on durable products, the utilization and reuse of materials, and consideration for end-of-life products. Concepts like upcycling and reusing materials and products are central to the fashion industry's shift towards Circular Economy, and a significant challenge lies in aligning values across the supply chain, particularly with those of consumers.

As consumers grow more concerned about sustainability, practices like upcycling or reusing materials are gaining popularity. However, within the fashion industry, consumers naturally only have awareness of what occurs at the retail stage and possess limited information about how their purchasing decisions impact the entire supply chain.

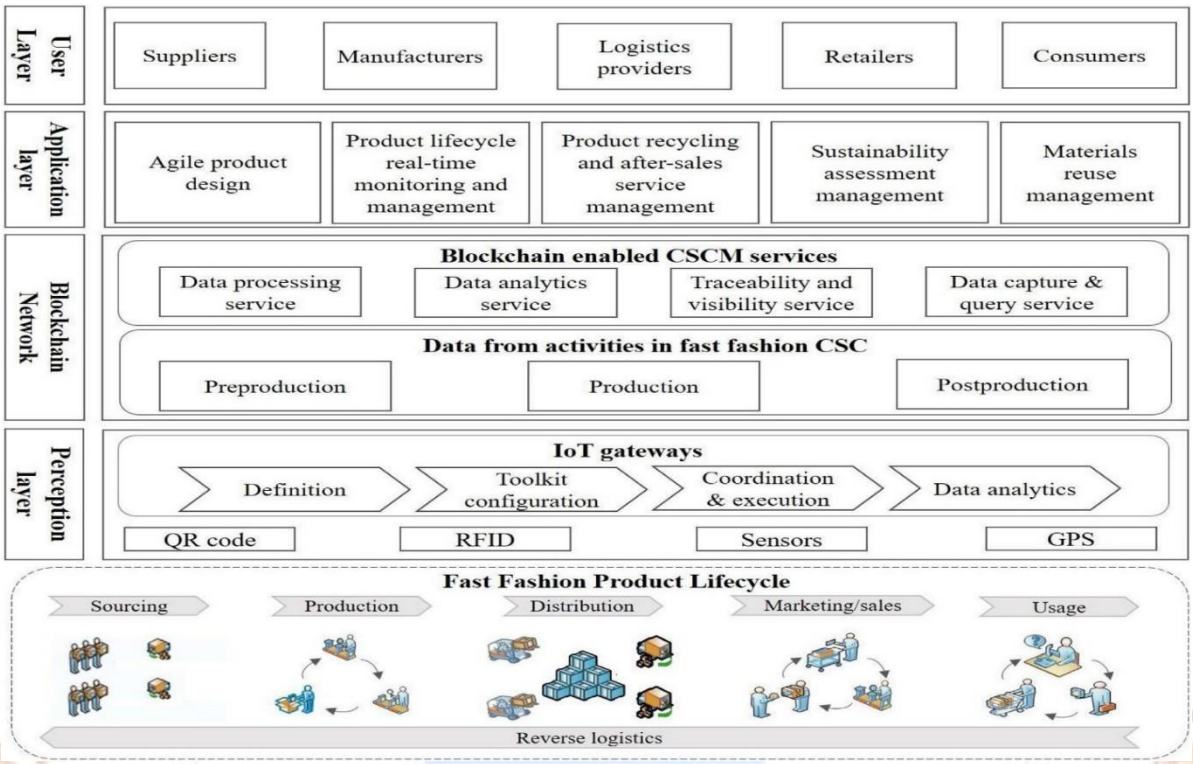

Fig.1 Flowchart of blockchain, fast fashion csc & fast fashion product lifecycle

2.5 Blockchain technology in circular supply chain management

The conventional sustainable SCM concept centers around minimalizing waste without placing significant emphasis on the reuse and restoration of raw materials and waste. In contrast, Circular Supply Chain Management concept integrates circular thinking and the principles of Circular Economy into Supply Chain Management. The goal of CSCM is to foster a zero-waste supply chain across all functions and partners, extending from natural material suppliers to final consumers.

2.5.1 Major sector of applying BCT in CSCM

- Resource Arrangement through Information Management
  Efficient information management facilitates swift adjustments for all stakeholders. Blockchain technology can bolster Circular Supply Chain Management by accelerating resource deployment, minimizing waste, and fortifying the resilience and adaptability of circular supply chains.
- Provider Assortment and Expansion
  Blockchain Technology can establish platforms and databases by recording historic performance data of all providers. Furthermore, BCT aids customers and providers in developing smart contracts to track and standard provider performance.
- Procurement
  Blockchain Technology can track and analyze the life cycle of products, empowering all Circular Supply Chain Management partners to simultaneously enhance resource efficiency and material supply resilience during the procurement process.
- Manufacturing and Operations
  Blockchain Technology can fully integrate internal production and operations information with external supply chain requirements. As a result, all Circular Supply Chain Management partners can accurately adjust and monitor their manufacturing and operations to meet the principles of the Circular Economy concept, such as the 3R principles.
- Materials Management
  Blockchain Technology facilitates extensive traceability of products and materials, significantly reducing losses during handling in logistics. This leads to shorter lead times and enhanced resource efficiency within the logistics operations.

2.5.2 Challenges and Potential Blockchain Technology Solutions

2.5.2.1 **Product Economics of Fast Fashion Products and Supply Chain**

Pre-Production Stage:

- Empower the establishment of a distributed network devoid of trust for sharing a distributed resource database.
- Empower supply chain participants to forecast demand collaboratively and efficiently, thus mitigating the bullwhip effect.

Production Stage:

- Provide the supply chain with enhanced security, speed, and scalability for distributing data among all actors, thereby minimizing inventory levels across the channel.

Post production stage:

- Reduce fraud, errors, transportation time, costs, and waste in the fashion product logistics.
- Diminish production inventory and associated packaging throughout the entire fast fashion supply chain.

2.5.2.2 **Environmental and social concerns associated with sustainable supplier selection**

Preproduction stage:

- Offer an enhanced method for assessing and choosing the appropriate suppliers.
- Introduce a system to automatically initiate actions, like supplier verification and certification, upon meeting predetermined conditions, thereby accelerating information flow between nodes.
- Supplier verification can be swiftly conducted, recorded, and accessed by all blockchain nodes.
- Consequently, a blockchain-based supplier selection process will become simpler, more efficient, and effective during the pre-production stage.

Production stage:

- Leveraging a blockchain-based record and traceability framework can uphold the three pillars of sustainability by monitoring and tracing events concerning ecological and social responsibilities.
- Evaluate the quality and safety of chemical usage, water consumption, and land use throughout production processes, while also scrutinizing manufacturing practices involving organic sources and technical fibers derived from nonrenewable chemical resources.
- Monitor working conditions and the status of workers by collecting environmental data like ambient, humidity, temperature, and tracking their working hours.
- Utilize this data to analyze, assess, certify, and re-certify whether suppliers have complied with ethical standards and requirements.

Post-production stage:

- Blockchain technology enables the verification, recording, tracking, and authentication of the production and usage history of fashion products. These products can undergo washing, sanitizing, and quality/brand audits, allowing for their resale, leasing, or donation to extend their lifespan.
- By employing blockchain verification and authentication, materials that are considered to have reached the end of their lifespan can be recycled and repurposed into new products. This approach maximizes the utilization of fast fashion products while simultaneously minimizing waste volumes.

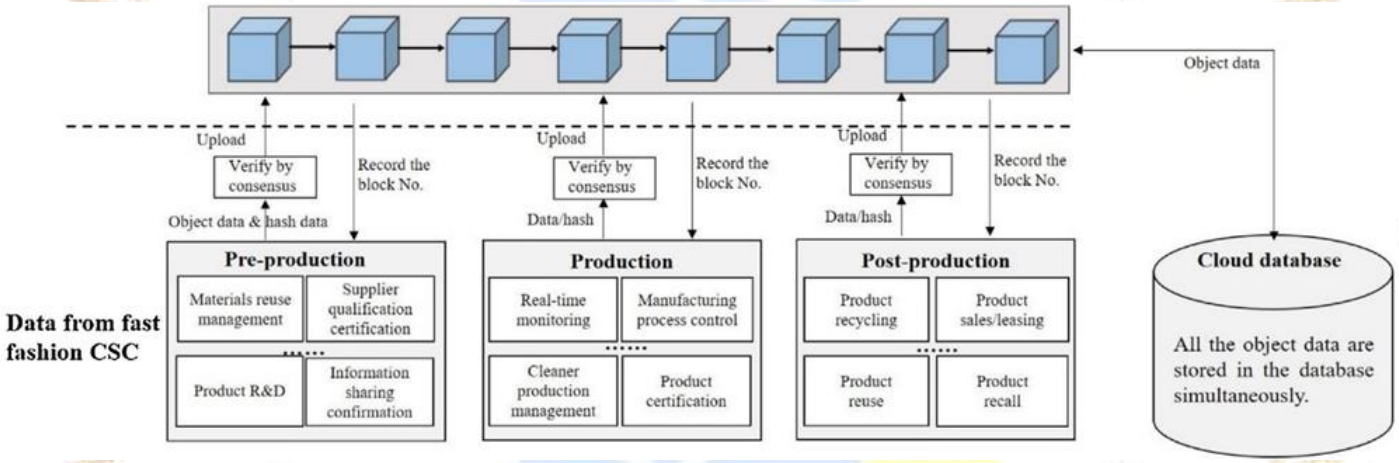

Fig.2 The data stream in circular supply chain

The customer layer primarily encompasses entities engaged in the circular supply chain: suppliers, manufacturers, logistics enterprises, retailers, and consumers. Certain manufacturers have consolidated their logistics systems and sales channels, effectively operating as both retailers and logistics firms. This direct link with suppliers upstream and customers downstream proves highly beneficial for a circular supply chain, facilitating more efficient data sharing and rapid market responses. For consumers, accessing product information—including certifications and environmental data—via various applications allows them to track their purchasing decisions. Moreover, consumers can optimize product utilization by opting for reuse, rental, or recycling alternatives.

3 Role of Technology in Fostering Circular Supply Chain Management (CSCM)

Recognizing the pivotal role of emerging and innovative technologies in facilitating the shift toward Circular Supply Chain Management is imperative, although research in this domain is relatively new. The term "Industry 4.0" signifies the fourth industrial revolution, marked by the integration of smart technologies such as artificial intelligence, IoT, augmented reality, Additive Manufacturing, and big data analytics contribute significantly to shaping Industry 4.0. Although research on integrating Industry 4.0 technologies into Circular Supply Chain Management (CSCM) is ongoing, substantial evidence indicates a promising trajectory in line with the Circular Economy vision. While the integration of these technologies into CSCM is in its infancy, their potential impact is clear, presenting opportunities to bolster supply chain transparency, efficiency, and sustainability in accordance with circular economy principles.

As a result of swift technological progress and the pervasive throwaway mentality in numerous consumer societies, Waste Electrical and Electronic Equipment (WEEE) has surfaced as a notable environmental issue in recent times. As highlighted by Cong et al. (2017b), a considerable fraction of the value that could be reclaimed from end-of-life products, like WEEE, is forfeited due to insufficient planning throughout the recovery process. Esmaeilian et al. (2018) introduced a waste management framework enabled by the Internet of Things (IoT) for creating smart and zero-waste sustainable cities. This framework establishes a connection between waste management and the entire product lifecycle. It is built upon four interlinked strategies: waste prevention, upstream waste separation, timely garbage collection, and efficient value recovery of collected waste.

On the other hand, Giurco et al. (2014) delved into prospective advancements in 3D printing and their potential implications for Circular Economy. However, owing to a dearth of supporting business cases, the discussion primarily centered around conceptual scenarios. Although it holds substantial promise for Circular Economy, the widespread adoption of 3D printing faces numerous obstacles (Garmulewicz et al., 2018). The sustainability and circularity implications of 3D printing remain uncertain, resulting in extra questions than answers.

An additional realm of investigation centers on the impact of big data in Circular Supply Chain Management. A recent study found that big data and predictive analytics exert a notable influence on supply chain sustainability performance. However, our examination identified only one article addressing the application of big data in Circular Economy: Jabbour et al. (2017) introduced a framework proposing the integration of large-scale data into CE research.

4 ZARA: FUTURE RESEARCH DIRECTIONS

Several specialized research topics within Circular Supply Chain Management, such as supply chain performance and end-of-life product management, have garnered increased care. However, to fully realize the potential of CSCM, further research on all aspects of the supply chain is necessary. Tackling a range of technical, procedural, and incentive challenges is vital to actualizing Circular Economy. As a result, we recommend directing research efforts towards areas critical to Circular Supply Chain Management that have been overlooked or received minimal attention. Table 1 offers a condensed overview of the significance of each research domain, the extent of knowledge gaps, the potential advantages of delving into each direction, and the pressing need for further research based on review outcomes. Given that Circular Economy (CE) presents a promising frontier in sustainable practices, advancing Circular Supply Chain Management in these identified domains will notably elevate Sustainable Supply Chain Management and Global Supply Chain Management, empowering businesses to attain elevated levels of sustainability performance.

4.1 Summary of future research directions in CSCM

Table 1 – Importance, knowledge gap, potential impact and urgency in future research of CSCM

Research Area	Importance	Knowledge gap	Potential impact	Urgency
Circular design	Very High	Very Large	Critical	Very Urgent
Procurement and CSCM	High	Very Large	Moderate	Urgent
Biodegradable packaging for CSCM	Very High	Large	Critical	Very Urgent
Circular supply chain collaboration and coordination	Very High	Large	Critical	Very Urgent
Identifying drivers and barriers of CSCM	Very High	Large	Critical	Very Urgent
Circular consumption	High	Large	Moderate	Urgent
Product liability and Producer's responsibility	Very High	Very Large	Critical	Very Urgent
Technologies for minimizing wastages	High	Very Large	Critical	Urgent

4.2 Design for circularity

It's clear that Circular Supply Chain Management (CSCM) necessitates a thorough overhaul of product, process, and supply chain design. At the heart of CSCM lies circular design, which entails CE-oriented enhancements in processes, supply chain design for End-of-Life management, and the adoption of innovative product design methods/techniques like Design for Disassembly (DFD), Design for Remanufacturing, and Design for Recycling. These realms offer abundant research opportunities.

4.3 Procurement and CSCM

Procurement stands as a pivotal strategic activity essential for a company's enduring prosperity. However, the integration of circular thinking into procurement has garnered less focus in comparison to other supply chain functions. To bolster life cycle extension, streamline resource recovery, and guide future research directions, Circular Supply Chain Management (CSCM) demands products imbued with novel or reinforced attributes such as durability, reliability, and reusability.

Table 2 – Importance, knowledge gap, urgency of potential impact in procurement and CSCM

Research Area	Importance	Knowledge gap	Urgency of Potential impact
Circular design	Critically High	Very Big	High
Biodegradable packaging for CSCM	Very Urgent	Critical	Very High
Procurement and CSCM	Large	Critical	Very Urgent
Circular supply chain collaboration and coordination	Very High	Large	Critical
CSCM driver and barrier identification	High	Big	Urgent
Product liability and Producer's responsibility	Very High	Very Large	Critical
Circular consumption	Very High	Very Large	Critical
Technologies for minimizing wastages	Very Urgent	Critical	Very High

This table outlines the importance, gap in knowledge, and urgency of potential impact for various research areas within CSCM. Each area is critical for advancing the circularity and sustainability of supply chains, with varying levels of urgency for further research and action.

4.4 Biodegradable packaging for CSCM

Annually, the production of millions of tons of non-biodegradable plastics for packaging presents substantial conservation challenges. For instance, in China, packaging waste ranks as the fourth most polluting source (Zhang and Zhao, 2012). The emerging paradigm of Circular Supply Chain Management (CSCM) underscores the need for packaging materials that are renewable, recyclable, and compostable. Moreover, these materials ought to be cost-effective and exhibit physical and chemical characteristics conducive to straightforward customization for diverse applications. Investing in the research and development of packaging solutions crafted from biodegradable materials harbors immense potential for expediting the transition to Circular Economies (CEs).

4.5 Circular supply chain collaboration and coordination

In a Circular Economy, waste residuals from one process or supply chain are repurposed as resources for another, underscoring the necessity for sustained collaboration not only among supply chain partners but also across supply chains (Flink, 2017). Several research opportunities abound in various areas:

1. Incentives and Strategic Value Alignment: Exploring incentives and strategies to align the values of different stakeholders towards circularity.
2. Collaboration and Coordination Mechanisms: Developing mechanisms for collaboration and coordination with all the business partners, BoG and internal communication.

4.6 Drivers and barriers of CSCM:

In different contexts, the factors propelling and impeding Circular Supply Chain Management (CSCM) are likely to differ. However, only a restricted number of studies have delved into these issues in particular industries, such as China's information technology (IT) and electronics sectors, as well as Finland's textile and retail industries. There is a crucial need for research to explore how cultural and industry-specific factors impact the drivers and barriers of Circular Supply Chain Management (CSCM). Furthermore, prioritizing the identification of causes and barriers in specific settings is essential for devising the most effective intervention measures to prevent or overcome them.

4.7 Circular consumption:

The consumer perspective on circular products has been largely neglected, despite a few early studies. There is a demand for more research to comprehend how circular items can be made more appealing to consumers. Creating marketing strategies that showcase product reliability, innovative features, warranties, and quality control mechanisms could contribute to shaping positive consumer perceptions of circular products. Given that many consumers are reluctant to return used products, it is crucial to explore methods and incentives that can influence consumer behavior and promote the circular economy.

4.8 Product liabilities and producer's responsibility:

To facilitate resource recovery through End-of-Life management, the progression of Circular Economies will necessitate systematic product take-back initiatives by producers. As a result, End-of-Life and waste management scenarios must address the following concerns:

- Liability stemming from the use of hazardous substances in the production or utilization of products, leading to new human and environmental health concerns;
- Liability arising from product malfunction;
- Responsibility for material mismanagement throughout the lifecycle(s) of substances utilized in product synthesis and manufacturing, as well as during product operation and material management in the EoL.

Additional research is required to assess the feasibility and effectiveness of implementing extended producer responsibility legislation, which holds producers accountable for their products even after they have been sold to end consumers. Alternatively, Product-Service Systems, a 'functional service' model in which producers retain ownership of physical goods while acting as service providers to meet end-user needs, offers an alternative approach.
Product-Service Systems (PSS) can be established to assist manufacturers in managing End-of-Life (EoL) processes. Within a shared economy, such systems have the potential to greatly reduce the necessity for production activities, consequently leading to significant reductions in environmental impacts.

4.9 Technologies and CSCM:

While technologies hold promise for sustainable development, there remains a dearth of research on their role in Circular Supply Chain Management (CSCM). A recent special issue of the Journal of Cleaner Production, titled "Improving Natural Resource Management and Human Health for Sustainable Societal Development in Big Data Environments," sheds light on this topic. However, despite focusing on waste prevention using the 3R concept within the circular economy framework, none of the papers in the collection applied circular reasoning. This highlights a significant opportunity for CSCM to explore the potential of big data analytics. Additionally, 3D printing has emerged as a promising technology, offering the potential for higher-efficiency and lesser-cost adapted manufacturing.

Moreover, the Internet of Things and Radio Frequency Identification technologies can be leveraged in CSCM to enhance traceability and information management across the entire lifecycle (Zhang et al., 2010). Additionally, it is imperative to integrate Circular Economy principles into the Enterprise Information Systems of businesses as soon as possible (Jensen and Remmen, 2017).

5 Conclusion

The increasing recognition of emerging visions and initiatives in conceptualizing and executing Circular Economies (CEs) as preferable alternatives to the traditional linear (take, make, dispose) economic model holds significant potential for assisting enterprises in achieving breakthroughs in sustainability performance. Consequently, researchers are showing a growing interest in integrating CE principles into Supply Chain Management (SCM).

However, there still exists a plethora of misconceptions surrounding the concepts of supply chain sustainability. This study identified the lack of awareness regarding the true scope of Circular Supply Chain Management and the strategic value of its research directions as a hindrance to the field's advancement. To address this, we established a comprehensive definition of CSCM based on existing literature and conducted a systematic review to gain a deeper considerate of the present state of CSCM research. The findings suggest a capable field with ample opportunities for further exploration towards achieving a zero-waste vision. This entails embracing restorative and regenerative processes, implementing suitable business models, and reorienting supply chain functions. Moreover, the study proposed future research directions depends on the significance of the research area, existing knowledge gaps, potential impact of future research, and the urgency for action and implementation. Ultimately, this study offers timely guidance to researchers, practitioners, and policymakers on how to effectively operationalize Circular Economies from a supply chain perspective, thereby significantly enhancing Sustainable Supply Chain Management and Global Supply Chain Management.

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