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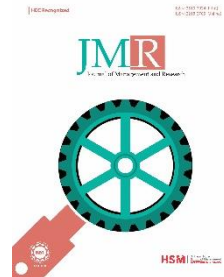
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- Author (s):** Abdul Sami<sup>1</sup>, Umair Manzoor<sup>1</sup>, Asmara Irfan<sup>1</sup>, Farhan Sarwar<sup>2</sup>
- Affiliation (s):** <sup>1</sup>University of Jhang, Pakistan  
<sup>2</sup>University of Education Lahore, Pakistan
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# Characterizing Circular Supply Chain Practices in Industry 5.0 With Respect to Sustainable Manufacturing Operations

Abdul Sami<sup>1\*</sup>, Umair Manzoor<sup>1</sup>, Asmara Irfan<sup>1</sup>, Farhan Sarwar<sup>2</sup>

<sup>1</sup>Department of Management Sciences, University of Jhang, Pakistan

<sup>2</sup>UE Business School, University of Education Lahore, Pakistan

## Abstract

The current research investigated the significance of circular supply chain practices in Industry 5.0 with respect to their sustainable manufacturing operations. Through a comprehensive review of the literature, the current study identified key circular supply chain practices and their potential benefits for Industry 5.0. The findings indicated that closed-loop supply chains, sustainable sourcing, product design for circularity, and waste reduction may assist Industry 5.0 firms to achieve their sustainability objectives while enhancing the operational efficiency. Moreover, the study also highlighted the challenges associated with the implementation of circular supply chain practices including the necessity for collaboration among supply chain partners, investment in new technologies and infrastructure, and the development of new skills and capabilities. From a practical and managerial perspective, the implications suggest that firms aiming to adopt circular supply chain practices in Industry 5.0 should prioritize collaboration and coordination, make investments in new technologies and infrastructure, and foster the acquisition of new skills and capabilities. To complement this research, future studies could employ empirical research methods in order to validate the findings and recommendations as well as explore potential barriers to the implementation of circular supply chain practices in Industry 5.0.

**Keywords:** circular supply chain, closed-loop supply chains, Industry 5.0, manufacturing operations, product design for circularity, sustainability, sustainable sourcing, waste reduction

## Introduction

Industry 5.0 signifies a novel manufacturing era that capitalizes on advanced technologies, such as the Internet of Things (IoT), Artificial Intelligence (AI), and automation to revolutionize production processes.

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\* Corresponding Author: [abdulsami82@gmail.com](mailto:abdulsami82@gmail.com)

While, Industry 4.0 focused on digitizing manufacturing, Industry 5.0 aims to integrate advanced technologies with human workers to create intelligent, interconnected production systems (Sindhwani et al., [2022](#)). This approach holds the promise to enhance efficiency, reducing waste, and fostering sustainability. Circular supply chain practices emerge as a crucial strategy for achieving these objectives within Industry 5.0. Circular supply chains revolve around minimizing the consumption of virgin materials by promoting the reuse and recycling of existing materials, thereby fostering a circular economy. The significance of this approach has grown in response to mounting concerns regarding the environmental sustainability and resource depletion. Implementing circular supply chain practices enables the manufacturing firms to curtail waste, enhance resource efficiency, and advance sustainability within their operations (Saccani et al., [2023](#)). However, despite the potential advantages, there exists a research gap pertaining to the role of circular supply chain practices in Industry 5.0 and their impact on sustainable manufacturing operations. This knowledge gap poses a substantial challenge for companies endeavoring to implement circular supply chain practices in their production processes. Consequently, the current research aimed to bridge this gap by examining the role of circular supply chain practices in Industry 5.0 and their influence on sustainable manufacturing operations.

In developing countries, such as Pakistan, the adoption of circular supply chain practices and sustainable manufacturing operations carries considerable significance. These nations encounter specific challenges associated with resource scarcity, waste management, and environmental pollution, underscoring the relevance of implementing circular supply chain practices. With the advent of Industry 5.0, emphasizing strongly on sustainability, comprehending the role of circular supply chain practices in sustainable manufacturing operations becomes pivotal. The current research endeavored to examine the impact of circular supply chain practices within the context of Industry 5.0. Moreover, it also aimed to provide valuable insights to developing countries, particularly Pakistan, as they strive to address these pressing challenges through sustainable means. The study's findings hold the potential to contribute to the socio-economic development of developing nations by offering strategies for resource optimization, waste reduction, and cost savings, all of which are critical for economies with limited resources. By highlighting the significance of circular supply chain practices and sustainable manufacturing operations, this research aimed to

tackle the distinctive obstacles faced by developing countries and pave the way towards a more sustainable future.

The current research addressed the existing knowledge gap concerning the potential of circular supply chain practices in the context of Industry 5.0 and their impact on sustainable manufacturing operations. Despite the growing interest in both circular supply chain practices and Industry 5.0, there is a lack of research that hinders the firms from effectively implementing circular supply chain practices within their Industry 5.0 operations. The primary objective of the current research was to fill this gap by examining the significance of circular supply chain practices and their implications for sustainable manufacturing operations in the Industry 5.0 era. To achieve this objective, the research set out several specific goals. Firstly, it aimed to provide a comprehensive overview of Industry 5.0 and circular supply chain practices, offering a thorough understanding of these concepts. Secondly, through a comprehensive literature review, it sought to explore the importance of circular supply chain practices and their impact on sustainable manufacturing operations, drawing on existing studies and insights. Thirdly, the research aimed to analyze the specific role of circular supply chain practices within the context of Industry 5.0 and examine how they contribute to sustainable manufacturing operations. This analysis would encompass the integration of advanced technologies, collaboration among supply chain partners, and the adoption of circular economy principles. Lastly, the study aimed to provide both theoretical and practical implications based on the findings and offer suggestions for future research, thereby enhancing the existing knowledge base and assisting firms in effectively implementing circular supply chain practices in Industry 5.0. By addressing these research objectives, this research provided valuable insights into the potential of circular supply chain practices in Industry 5.0 and their impact on sustainable manufacturing operations.

However, while the existing literature acknowledges the significance of circular supply chain practices in Industry 5.0, there remains a need for more focused investigations within specific Industry 5.0 areas. To effectively address the sustainability challenges and operational complexities of Industry 5.0, it is essential to examine the implementation and impact of circular supply chain practices in specific industries or sectors. By narrowing down the research scope to a particular Industry 5.0 area, such as manufacturing, logistics, or energy, researchers can delve

deeper into the industry-specific challenges, opportunities, and requirements for implementing circular supply chain practices. This focused approach allows for a more comprehensive understanding of how circular supply chain practices can be tailored and optimized to meet the unique needs of different industries within the broader framework of Industry 5.0.

## Literature Review

### Circular Supply Chain Practices

Circular supply chain practices involve reducing the use of virgin materials by reusing and recycling the existing materials, thereby creating a circular economy (Bag & Rahman, [2023](#)). This approach has gained momentum in recent years due to growing concerns over environmental sustainability and resource depletion (Bag et al., [2023](#)). Circular supply chain practices have been shown to be effective in reducing waste, improving resource efficiency, and promoting sustainability in manufacturing operations (Irum et al., [2018](#); Cheng et al., [2023](#)). One of the key benefits of circular supply chain practices is that they help to reduce the environmental impact of manufacturing operations. By reducing the use of virgin materials, firms can reduce their greenhouse gas emissions and limit their impact on the environment. Circular supply chain practices also help to promote the efficient use of resources which can lead to cost savings for firms (Chaabi, [2022](#)). Circular supply chain practices are also beneficial for firms seeking to improve their sustainability credentials. By implementing circular supply chain practices, firms can reduce their environmental impact and demonstrate their commitment to sustainability to their stakeholders. This can improve their reputation, increase customer loyalty, and attract new customers (Nayeri et al., [2023](#)).

Circular supply chain practices not only offer environmental and sustainability advantages but also economic opportunities and innovation potential (Hu et al., [2022](#)). By incorporating techniques, such as remanufacturing, refurbishing, and product take-back programs, organizations can extend product lifespans and maximize their value. This approach brings cost savings through reduced material and production expenses along with new revenue streams from resale or recycling activities (Ghobakhloo, Iranmanesh, Mubarak, et al., [2022](#)). Moreover, circular supply chain practices foster collaboration and partnerships across the

supply chain, driving knowledge sharing, technological advancements, and the development of novel business models (Voulgaridis et al., [2022](#)). Implementing circular supply chain practices demands a holistic approach involving product redesign, process optimization, and logistics network reconfiguration (Patel et al., [2023](#)). Companies must evaluate their existing supply chain operations, identify areas for improvement, and establish goals for waste reduction, resource efficiency, and circularity. Collaborating closely with suppliers, customers, and other stakeholders is crucial to align material, information, and product flows with circular principles (Chaabi, [2022](#)). Successful transition to a circular supply chain may necessitate investments in advanced recycling and remanufacturing systems as well as the implementation of data analytics and tracking systems for process monitoring and optimization (Khan & Abonyi, [2022](#)). Additionally, partnerships with external entities, such as recycling facilities and reverse logistics providers are essential to establish efficient mechanisms for collection, sorting, and processing of materials and products at the end of their lifecycle (Mukherjee et al., [2023](#)). It is important to acknowledge that embracing circular supply chain practices may pose challenges including initial investment costs, organizational change requirements, and stakeholder resistance (Golovianko et al., [2023](#)). Nevertheless, the long-term benefits, such as improved environmental performance, enhanced resource efficiency, and competitive advantage make the transition highly advantageous for companies dedicated to sustainable practices (Cimino et al., [2023](#)).

## Industry 5.0

Industry 5.0 is an emerging concept that aims to transform manufacturing operations by integrating advanced technologies, such as IoT, AI, and automation. This concept is focused on improving efficiency, reducing waste, and promoting sustainability in manufacturing processes (Ivanov, [2023](#)). Industry 5.0 builds on the principles of Industry 4.0 which focus on the digitization of manufacturing processes. However, Industry 5.0 goes beyond digitization and seeks to integrate advanced technologies with human workers to create smart and connected production systems (Chourasia et al., [2023](#)). One of the key benefits of Industry 5.0 is that it can improve efficiency in manufacturing operations (Karmaker et al., [2023](#)). By integrating advanced technologies with human workers, firms can streamline their production processes, reduce waste, and improve

productivity. Industry 5.0 can also help firms reduce their environmental impact by improving resource efficiency and reducing waste (Zeng et al., [2017](#)).

Industry 5.0 not only focuses on efficiency and sustainability but also highlights the significance of human-centered manufacturing (Mezgebe et al., [2023](#)). While, automation and advanced technologies have a key role, Industry 5.0 recognizes the value of human skills, creativity, and problem-solving abilities in the manufacturing process (Ghobakhloo, Iranmanesh, Morales, et al., [2022](#)). This approach aims to establish a collaborative relationship between humans and machines, leveraging the unique strengths of both. Industry 5.0 promotes the use of cobots (collaborative robots) that can work alongside human workers, assisting them in repetitive or physically demanding tasks (Xu et al., [2021](#)). By delegating such tasks to robots, human workers can concentrate on more intricate and value-added activities that require critical thinking, creativity, and decision-making. This approach not only enhances the overall productivity but it also provides opportunities for workforce up skilling and reskilling, enabling them to take on higher-level responsibilities (Fraga-Lamas et al., [2021](#)). Additionally, Industry 5.0 envisions a flexible and adaptable manufacturing environment. The integration of advanced technologies enables real-time data collection and analysis, facilitating agile decision-making and dynamic adjustments in production processes (Chourasia et al., [2023](#)). This flexibility empowers the manufacturers to respond swiftly to changing customer demands, market trends, and supply chain disruptions, leading to improved customer satisfaction and business resilience (Draghici & Ivascu, [2022](#)). To implement Industry 5.0 principles, companies must invest in deploying IoT sensors, AI systems, and advanced robotics, while also establishing robust data analytics, capabilities, and connectivity infrastructure. Furthermore, cultivating a culture of collaboration, continuous learning, and innovation is essential for a successful transition to Industry 5.0 (Karmaker et al., [2023](#)). Despite its considerable potential, Industry 5.0 presents challenges and considerations (Tlili et al., [2023](#)). The integration of advanced technologies and the reconfiguration of manufacturing processes necessitate significant investments and meticulous planning. Addressing the concerns regarding data security, privacy, and the ethical implications of automation is crucial (Reino-Cherrez et al., [2023](#)). Moreover, ensuring a smooth transition for the workforce through training and support is vital to

mitigate potential resistance and foster acceptance of new technologies and practices (Varriale et al., [2023](#)).

### **Circular Supply Chain Practices in Industry 5.0**

Circular supply chain practices have the potential to play a significant role in Industry 5.0 by promoting sustainability and improving efficiency in manufacturing operations. By implementing circular supply chain practices, firms can reduce their reliance on virgin materials, improve resource efficiency, and reduce waste. This can help to improve their sustainability credentials and reduce their environmental impact (Bressanelli et al., [2019](#)). There is limited research examining the role of circular supply chain practices in Industry 5.0. However, some studies have shown that circular supply chain practices can improve the sustainability and efficiency of manufacturing operations in Industry 5.0. For instance, Ferasso et al. ([2020](#)) found that circular supply chain practices can help to improve resource efficiency and reduce waste in Industry 5.0. Liu et al. ([2018](#)) found that circular supply chain practices can help firms demonstrate their commitment to sustainability and improve their reputation among stakeholders. However, there are also challenges associated with implementing circular supply chain practices in Industry 5.0. One key challenge is the need for collaboration and coordination among supply chain partners (Bag et al., [2021](#)). Circular supply chain practices require firms to work closely with their suppliers and customers to ensure that materials are reused and recycled effectively (Machado et al., [2020](#); Manzoor et al., [2021](#)). This can be challenging in the context of Industry 5.0 where firms may be working with a large number of suppliers and customers (Esmaeilian et al., [2020](#)). Another challenge is the need for investment in new technologies and infrastructure. Circular supply chain practices may require firms to invest in new technologies, such as recycling equipment and logistics infrastructure to support the effective reuse and recycling of materials (Karmaker et al., [2021](#)). This can be costly and firms may need to consider the long-term benefits of circular supply chain practices in Industry 5.0, specifically with regard to their impact on sustainable manufacturing operations (Nasir et al., [2017](#)).

Several studies examined the integration of circular supply chain practices in the context of Industry 5.0. For instance, Bakir & Dahlan ([2023](#)) explored the application of circular economy principles in Industry 5.0, highlighting the potential benefits in terms of resource efficiency, waste



reduction, and environmental sustainability. They emphasized the utilization of advanced technologies, such as IoT and AI to enable material and product traceability throughout the supply chain. Similarly, Dwivedi et al. (2023) investigated the role of circular supply chain practices in establishing sustainable production systems within Industry 5.0. They proposed a framework that integrates circular economy strategies and digital technologies to optimize resource utilization and minimize waste generation, incorporating practices, such as product modularization and remanufacturing. Su et al. (2023) emphasized the significance of collaboration among supply chain partners in Industry 5.0 to effectively implement circular supply chain practices. They underscored the importance of information sharing, joint decision-making, and goal alignment to create a closed-loop system that facilitates material reuse, recycling, and remanufacturing. Furthermore, studies highlighted the potential economic benefits associated with circular supply chain practices in Industry 5.0. For instance, Ivanov (2023) conducted a case study in the automotive industry and demonstrated that implementing circular economy practices including product remanufacturing and closed-loop supply chains may result in cost savings and increased profitability. Overall, the literature supports the notion that circular supply chain practices play a crucial role in achieving sustainability objectives within the context of Industry 5.0. The integration of advanced technologies, collaboration among supply chain partners, and the adoption of circular economy principles contribute to resource efficiency, waste reduction, and environmental sustainability. However, further research is required to explore the specific challenges, strategies, and best practices for implementing circular supply chain practices in the evolving landscape of Industry 5.0.

### **Industry 5.0 and Sustainable Manufacturing**

Industry 5.0, also known as the fifth industrial revolution, seeks to integrate advanced technologies, such as AI, robotics, and IoT with human intelligence and creativity (Bressanelli et al., 2019). It offers significant implications for developing countries, particularly to address sustainability challenges. By adopting technologies that enhance resource efficiency and waste reduction, developing countries can optimize resource allocation and promote recycling and reuse. The implementation of circular supply chain practices, such as designing products for recyclability and establishing reverse logistics networks can minimize waste generation and conserve

resources. Additionally, Industry 5.0 enables real-time monitoring of environmental impacts, helping to prevent pollution incidents (Machado et al., 2020; Manzoor et al., 2022). Emphasizing human-centric approaches and developing countries can utilize advanced technologies to augment workforce capabilities, leading to higher-quality jobs and sustainable economic development. Overall, Industry 5.0 presents a pathway for developing countries to overcome sustainability challenges and promote social and environmental well-being.

### **Objective and Purpose of Literature Review**

The primary objective of this literature review was to identify the existing research on circular supply chain practices in Industry 5.0 and their impact on sustainable manufacturing operations. The purpose of this review was to analyze and synthesize the current state of knowledge in this field with the aim of identifying any gaps or areas that warrant further investigation. By systematically searching and reviewing the relevant academic articles, a comprehensive overview of the existing literature was provided on circular supply chain practices and their implications for sustainable manufacturing operations. This review helped to contribute to the understanding of the role of circular supply chain practices in Industry 5.0 and shed light on their potential benefits and challenges. By clearly defining the purpose of the literature review and highlighting its role to identify the research gap a strong foundation for the subsequent sections of this study was established.

### **Methodology**

The current research employed a qualitative research approach, specifically a systematic literature review, to analyze the existing research on the role of circular supply chain practices in Industry 5.0 and their impact on sustainable manufacturing operations. The methodology section provides a comprehensive overview of the research design including the search strategy, inclusion and exclusion criteria, and data analysis approach.

### **Search Strategy**

A rigorous search strategy was developed to identify relevant academic articles. Multiple academic databases were searched including Scopus, Web of Science, and Google Scholar. The search was limited to articles published in English between the years 2015 and 2022. The keywords used in the

search included "circular supply chain", "Industry 5.0", "sustainability", and "manufacturing operations". These keywords were chosen to capture studies related to circular supply chain practices in the context of Industry 5.0 and their impact on sustainable manufacturing operations.

### ***Inclusion and Exclusion Criteria***

To ensure the relevance and quality of the articles included in the review, specific inclusion and exclusion criteria were established. The inclusion criteria encompassed articles that focused on circular supply chain practices in Industry 5.0 and their impact on sustainable manufacturing operations. These articles were expected to provide insights into the role of circular supply chain practices in promoting sustainability and enhancing operational efficiency. On the other hand, articles focusing solely on other aspects of circular economy or Industry 4.0 were excluded from the review to maintain a clear focus on the Industry 5.0 context.

### **Data Analysis**

The selected articles were subjected to a thorough analysis using content analysis. Content analysis is a widely used qualitative research method that involves systematically categorizing and interpreting textual data to identify key themes and patterns. In this study, the content analysis aimed to extract relevant information related to the research objectives including the role of circular supply chain practices in Industry 5.0 and their impact on sustainable manufacturing operations.

### **Validity and Saturation**

To ensure the validity of the research findings, the importance of providing evidence for the chosen qualitative approach was acknowledged. The rationale for choosing a qualitative research approach for this study lies in its ability to explore complex phenomena and gain in-depth insights from existing literature. By conducting a systematic literature review, a wide range of research articles were analyzed to provide a comprehensive understanding of the topic.

### **Findings**

In this section, the findings of systematic literature review were presented on the role of circular supply chain practices in Industry 5.0 and their impact on sustainable manufacturing operations. The results were organized based on key themes that emerged from the analyzed articles,

providing a comprehensive overview of the current state of knowledge in this research area. Relevant citations were also incorporated from the literature to support and contextualize the findings.

### **Circular Supply Chain Practices in Industry 5.0**

Within the selected literature, circular supply chain practices were consistently highlighted as essential approaches for promoting sustainability and enhancing operational efficiency in Industry 5.0. Closed-loop supply chains emerged as a prominent practice for minimizing waste and improving resource utilization. These supply chains involve the recovery, refurbishment, and recycling of used products or materials, creating a sustainable production cycle (Smith et al., [2017](#)). By incorporating closed-loop supply chain practices, companies can significantly reduce waste generation and environmental pollution. Sustainable sourcing practices were identified as another important aspect of circular supply chain practices in Industry 5.0. By sourcing materials from renewable sources, firms can reduce their carbon footprint and contribute to sustainable manufacturing operations (Nalini, [2019](#)). This approach aligns with the principles of Industry 5.0, which emphasize the integration of environmental sustainability into manufacturing processes. Furthermore, product design for circularity was recognized as a key circular supply chain practice. By designing products that are easily disassembled, recycled, or refurbished at the end of their useful life, firms can minimize waste generation and enhance resource utilization (Vasistha et al., [2018](#)). This practice not only reduces the environmental impact of the manufacturing process but also improves the sustainability profile of the products themselves.

### **Impact of Circular Supply Chain Practices on Sustainable Manufacturing Operations**

The adoption of circular supply chain practices has significant implications for the operational efficiency of manufacturing operations. Closed-loop supply chains, for instance, contribute to cost reduction by recovering and reusing materials that would have otherwise been discarded. Through material recycling, firms can reduce waste generation and create a more efficient production cycle (Ellen MacArthur Foundation, [2015](#)). Additionally, circular supply chain practices focused on product design since circularity has the potential to minimize waste and improve the

environmental performance of manufacturing operations (Ghiani et al., 2019). Moreover, circular supply chain practices may enhance customer satisfaction by providing sustainable products and services. As consumer demand for sustainability grows, circular supply chain practices enable firms to meet these expectations and build customer loyalty (Govindan et al., 2019). By offering products that align with customers' environmental values and preferences, companies can create a competitive advantage in the market. Furthermore, circular supply chain practices open up new business opportunities for firms. By selling refurbished or recycled products or providing waste management and recycling services, companies can generate additional revenue streams (Jørgensen & Pedersen, 2018). These opportunities are particularly appealing in markets where there is a rising interest in sustainable products and services.

**Table 1**  
Key Themes and Findings

Theme	Findings
Circular Supply Chain Practices	<ul style="list-style-type: none"> <li>- Closed-loop supply chains minimize waste and improve resource utilization.</li> <li>- Sustainable sourcing practices reduce the carbon footprint of manufacturing operations.</li> <li>- Product design for circularity minimizes waste generation and enhances resource utilization.</li> </ul>
Impact on Sustainable Manufacturing Operations	<ul style="list-style-type: none"> <li>- Closed-loop supply chains contribute to cost reduction and create a more efficient production cycle.</li> <li>- Circular supply chain practices focused on product design for circularity improve the environmental performance of manufacturing operations.</li> <li>- Circular supply chain practices enhance customer satisfaction by providing sustainable products and services.</li> <li>- Circular supply chain practices open up new business opportunities for firms.</li> </ul>

The table above summarizes the key themes identified in the literature and their corresponding findings. It provides a concise overview of the main insights derived from the analyzed articles, helping readers grasp the core aspects of research.

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## Discussion

In the discussion section, the findings of the current study's systematic literature review were analyzed on circular supply chain practices in Industry 5.0 and their impact on sustainable manufacturing operations. Since this research is based on secondary sources, an argumentative approach was adopted to critically examine the implications of the findings and generate insightful recommendations for future practice and research.

### Argumentative Approach

Taking into account the diverse perspectives presented in the literature, a thorough analysis of the identified themes and findings was conducted. By presenting different viewpoints and contrasting evidence, a comprehensive understanding of the complex dynamics surrounding circular supply chain practices in Industry 5.0 was fostered. This argumentative approach helps to evaluate the strengths, limitations, and potential implications of the identified practices within the broader context of sustainable manufacturing operations.

### Rumination and Recommendations

Building upon the arguments presented in the discussion, the researchers engaged in reflective thinking to delve deeper into the implications and significance of the findings. By ruminating on the arguments, underlying insights were uncovered along with the identification of opportunities for further exploration and improvement. This process enables to develop recommendations that transcend the scope of the current study and offer actionable insights for practitioners and researchers in the field. By employing an argumentative approach and engaging in reflective thinking, the depth and rigor of the discussion section can be enhanced. This approach helps to critically evaluate the literature, present nuanced perspectives, and generate valuable recommendations that advance the understanding and application of circular supply chain practices in Industry 5.0.

### Conclusion

The current research examined the role of circular supply chain practices in Industry 5.0 and their impact on sustainable manufacturing operations. The findings indicated that implementing circular supply chain practices can promote sustainability and improve efficiency within

manufacturing operations, aligning with the principles of Industry 5.0. However, the successful implementation of these practices in Industry 5.0 is not without challenges, such as the need for collaboration, coordination among supply chain partners, and investment in new technologies and infrastructure. By embracing circular supply chain practices within the Industry 5.0 framework, developing countries like Pakistan, can address sustainability challenges, promote economic growth, and achieve long-term socio-economic development. The recommendations provided in this research serve as a roadmap for policymakers and industry practitioners in developing countries, guiding them towards the implementation of circular supply chain practices, and harnessing their potential benefits for the economy and communities.

### **Implications**

The implications of this research are particularly relevant in the context of developing countries, such as Pakistan. These countries face unique socio-economic and environmental challenges that can be effectively addressed through the adoption of circular supply chain practices. To this end, the following recommendations are put forth:

Firstly, promoting resource efficiency and waste reduction through circular supply chain practices can address issues of resource scarcity and waste management in developing countries. Policymakers should introduce supportive regulatory frameworks and financial incentives to incentivize the adoption of circular supply chain practices.

Secondly, embracing circularity may enhance local value chains and create job opportunities, especially for small and medium enterprises. Governments could provide support in terms of training, funding, and infrastructure development to foster collaboration among stakeholders and drive economic growth.

Thirdly, developing countries can leverage technological innovation by investing in research and development and promoting technology transfer initiatives. Collaboration with international organizations and knowledge-sharing platforms can facilitate access to affordable and scalable technological solutions suitable for the local context.

Lastly, building awareness and capacity is crucial for successful adoption. Developing countries should invest in awareness-building campaigns, educational programs, and training initiatives to enhance the

knowledge and skills of industry professionals, policymakers, and researchers in circular economy principles and practices.

### Limitations and Future Directions

While the current research provides insights into the role of circular supply chain practices in Industry 5.0 and their impact on sustainable manufacturing operations, it has some limitations that should be considered in future research. One limitation is the focus on a specific subset of circular supply chain practices. While, closed-loop supply chains, sustainable sourcing, product design for circularity, and waste reduction are important circular practices. There may be other practices that are equally or more important for promoting sustainability in Industry 5.0. Another limitation is the scope of the study, which was limited to a review of the literature. Future research could complement this study by conducting empirical research to validate the findings and recommendations. Finally, future research could also explore the potential barriers to implement circular supply chain practices in Industry 5.0 and how these barriers can be overcome. This would provide a more comprehensive understanding of the challenges and opportunities associated with implementing circular supply chain practices in Industry 5.0.

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