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Designing Value Chains for Industry 4.0 and a Circular Economy: A Review of the Literature

Usama Awan [1,2], Robert Sroufe [2,*] and Karoly Bozan [3]

1 Industrial Engineering and Management, Lappeenranta-Lahti University of Technology, 53850 Lappeenranta, Finland; usama.awan@lut.fi
2 Donahue Graduate School of Business, Duquesne University, Rockwell Hall, 600 Forbes Avenue, Pittsburgh, PA 15282, USA
3 Palumbo-Donahue School of Business, Duquesne University, Rockwell Hall, 600 Forbes Avenue, Pittsburgh, PA 15282, USA; bozank@duq.edu
* Correspondence: sroufer@duq.edu

Abstract: The growth of emerging digital technologies has led to premature and inconsistent conclusions about the relationship between circular economy and value chain activities. A structured, systematic review approach was used to examine the titles and abstracts of 912 papers from the circular economy and digital transformation, strategic management, and operations management literature. We looked at a relevant selection of 79 articles to develop a research agenda. The literature review helped identify strategic initiatives impacting the firm value chain's redesign involving logistics capabilities, marketing, sales, and service. Outcomes of this study make significant contributions to the field. First, firms must reorganize their business models that align with their value chain activities. Second, the literature review in this study adds to a growing understanding of the field of research by showing that engaging with Industry 4.0 and the circular economy is desirable and necessary for internalizing knowledge flows across different value chain actors. Third, this study is a first step in the right direction in developing and understanding the critical role of value chains and evolving business models in a global economy with calls for more sustainable development.

Keywords: circular economy; digitalization; Industry 4.0; manufacturing; sustainable development; value chain

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1. Introduction

The fourth industrial revolution and the term Industry 4.0 (I4.0) involves the level of organization and control over the value chain of the life cycle of products. It is geared toward increasingly individualized customer requirements [1]. This I4.0 paradigm provides opportunities to move toward more sustainable and circular production models. These models are within the emerging circular economy (CE) instead of traditional, linear, take–make–use–dispose manufacturing systems. Understanding the value chain's circular relationships can help manufacturers devise ecofriendly initiatives [2]. For this study, we adopt the following definition of the CE: "the set of organizational planning processes for creating, delivering products, components, and materials at their highest utility for customers and society through effective and efficient utilization of ecosystem, economic, and product cycles by closing loops for all the related resource flows" [3] (p. 859). We know the CE can be seen from different points of view, e.g., Ghisellini et al. look at this as "an industrial economy aiming at enhanced sustainability through restorative intent and design" [4], while Alhawari and Awan highlight the implications the CE has for product life cycles with opportunities to better understand "practices aimed to keep products in use as long as possible even after the end of their lives" [3] (p. 22).

Future CE initiatives have opportunities and challenges that depend on applying new digital technologies [5]. The I4.0's emerging technology can improve productivity and provide smarter products, devices, and services, which assist businesses and their value chains and reduce environmental impacts [6,7]. Yet, the growth of emerging digital technologies has led to premature and inconsistent conclusions about the relationship between CE and value chain activities [8]. The increasing interest of practitioners and scholars in closing material loops with new technologies creates more questions than answers when understanding the complex relationships of I4.0 and the CE. With interest in and the evolution of the I4.0 field, there is now an opportunity to improve knowledge and understand the impacts of a manufacturer's value chain activities within this evolving paradigm [8]. A key element of I.40 and CE business models is understanding the enabling technology [9].

Digital technology can help align new phenomena such as I4.0 and CE impacts on manufacturing firms. Yet, there is a lack of understanding of how firms should implement I4.0 and CE models in their existing value chain [10]. According to Weking et al. [11], value chains are changing with "shifts from mass-produced, expert-designed goods, to mass-individualized, user-designed products" (p. 7). Integrating data, technology, and waste reduction across business functions and enterprises will be essential for enabling more sustainable business practices [12]. Further integration of a value chain is critical for closed-loop capabilities [13]. To date, the CE and life cycle management of materials enabled by new technologies research in this field has mainly focused on: assessing the relationship between I4.0 and the CE, lean manufacturing and the CE, l4.0 for sustainable manufacturing, creating skills and activities, closing material loops in the supply chain, supplier selection, along with new industrial production systems [5,8,14–16]. In addition, there has been little consideration of the strategic technology embedded in the value chain to drive economic growth [17].

Further, Ciliberto et al. [18] explored I4.0 dimensions by focusing on firm infrastructure and services operations. Awan et al. [19] go on to suggest that "future research studies should explore how Industry 4.0 and the circular economy together support the governance value chain" (p. 2055). There is an established understanding that the value chain activities are crucial for manufacturers to seize new opportunities and sustain competitive advantage. There has been a constant increase in the number of studies on the prospects for the CE brought about by I4.0. The research is scattered, and there have only been a few efforts on the role of I4.0 supporting value chain activities in the CE. However, there is a lack of clarity on how I4.0 and the CE affect manufacturers' value chain activities. Despite the increasing number of literature reviews, the research in this domain is limited in two primary ways:

- The prior literature reviews do not typically explore the digital CE in the value chain.
- There is little evidence of leveraging I4.0 and the CE to design value chain activities.

Researchers and practitioners need a holistic understanding of the literature given the above limitations. There is a need to try and understand the interface of I4.0 and the CE and its effect on value chain activities from a manufacturer's perspective. Sroufe [20] noted that sustainability is integrated within all business functions and product life cycles. Therefore, it is important to look at emerging business phenomena such as I4.0 and the CE to see where and how they disrupt business models, and moreover, how technology can be an enabler, and propose further integration opportunities for sustainable development [21]. Our work in this study has two objectives. The first objective is to analyze the I4.0 literature from a CE and value chain perspective. The second is to develop a research agenda focused on the intersection of I4.0 and the CE that goes beyond business as usual to provide opportunities for sustainable development. These objectives and primary research questions call for a close look at the literature and focused research questions. The first question involves understanding the conceptual connections made in previous studies on I4.0 and the CE with a value chain perspective. The second question asks what the literature says about the future of research in this evolving field when focusing on the value chain and a manufacturer's perspective. The answers to these questions will guide academics' and practitioners' understanding of the strategic importance of including I4.0 and an emerging CE contest in the design of their value chains.

To the best of our knowledge, there have not been systematic reviews on the intersection of I4.0, the CE, and effects on value chain activities from a manufacturer's perspective. Therefore, this research contributes to synthesizing the existing literature and developing a research agenda for value chains within the I4.0 and CE context. This study contributes to the CE field by: (1) identifying and analyzing how and why I4.0 and CE aspects have evolved in the design and management of value chains; (2) reviewing common themes and gaps in the literature; (3) shedding light on research opportunities and questions to be investigated by scholars, and (4) illustrating opportunities to evaluate a firm's readiness toward increasing automation and a digital transformation. These contributions help researchers and practitioners understand the transformation of an organization's activities, processes, competencies, and models to fully harness the impact of digital technologies while preserving the firm's viability in the future.

The structure of the study is as follows: it starts with an overview of I4.0 and the CE, followed by a description of the methodological approach of the relevant literature search within SCOPUS and Web of Science. Next, the analysis focuses on the interlinkages between the CE and value chain in I4.0 while future research opportunities are identified. Finally, the literature analysis is followed by discussing theoretical and practical contributions and conclusions.

2. Methods

For an organized review of existing literature on I4.0 and the CE, the methods used followed a systematic review [22]. This study's methods follow the guidelines of [23] to classify previous research and pose questions that provide insight and future research opportunities. According to Torraco [24], a literature review "is a form of research that reviews, critiques, and synthesizes representative literature on a topic in an integrated way such that new frameworks and perspectives on the topic can be generated" (p. 356). A systematic review of the literature helps to reduce bias in identifying, selecting, and evaluating relevant articles, according to Coope [25], to answer specific research questions [26]. Thus, a systematic review helps us understand previous work and provides novel insights into advances within a particular field of study [27]. This review involved multiple researchers and used tested, reliable review methods to avoid subjective bias.

The review allowed us to uncover the key findings of complex literature in the I4.0 and CE domains while providing a rigorous and transparent approach to comparing the available research findings to develop directions for future research [28]. These literature review studies have taken a look at the growing discussion about the CE and I4.0 and have emphasized the positive linkage of I4.0 and the CE [29]. Therefore, we adopted a systematic literature review approach on the subject following the recommendations by [30]. Next was the development of a list of keywords from published systematic literature reviews involving the CE and I4.0 [31], which can be found in Table 1, indicating the number of articles retrieved from Scopus and the Web of Science databases.

The Web of Science database was used to identify the primary research articles included in our review because of these databases' comprehensive coverage and reliability [32]. Despite the importance of the citation index, this database did not include all the relevant journals in the field. The initial literature search was followed by searching SCOPUS. Focusing on both Scopus and Web of Science databases gives broader access to peer reviewed published articles and helps access high-quality articles published in a scientific domain.

Only publications in well-respected academic journals were included, and the process excluded non-peer-reviewed journal publications, conference proceedings, and book chapters. The retained articles were from targeted search words in the title, abstract, or keywords in this study. These keywords covered the I4.0 aspect of the literature search: internet of things, industrial internet of things, smart factory, and I4.0. Only articles published in

English were included. Only full-length articles were considered in our sample, and these were rechecked for relevance and reliability. Figure 1 shows the article selection process.

Table 1. Key term search and resulting documents.

ID	Query	Web of Science™ Documents by Topic	Scopus™ Documents by Title, Abstract, and Keywords
1	TITLE-KEY (Industry 4.0 AND application AND Circular Economy) AND (LIMIT-TO (LANGUAGE, "English"))	16	28
2	TITLE-KEY (Industry 4.0 AND application AND internet of things) AND (LIMIT-TO (LANGUAGE, "English"))	502	620
	TITLE-KEY (Circular Economy AND Value Chain) AND (LIMIT-TO (LANGUAGE, "English"))	96	129
	TITLE-KEY (Circular business model AND Value Chain) AND (LIMIT-TO (LANGUAGE, "English"))	29	35
3	TITLE-KEY (Fourth Industrial Revolution AND application AND industrial internet of things) AND (LIMIT-TO (LANGUAGE, "English"))	68	88
4	TITLE-KEY (Industry 4.0 AND Business Model) AND (LIMIT-TO (LANGUAGE, "English"))	510	552
5	TITLE-KEY (Internet of things AND Fourth Industrial Revolution AND Business Model) AND (LIMIT-TO (LANGUAGE, "English"))	44	61
6	TITLE-KEY (Circular Economy AND Business Model) AND (LIMIT-TO (LANGUAGE, "English"))	26	43
7	TITLE-KEY (Circular business model AND IoT) AND (LIMIT-TO (LANGUAGE, "English"))	23	34
	Key term search performed on 4 August 2021		

The exported articles from the Web of Science and Scopus records were moved into Mendeley software for a duplication check and data management. After applying the inclusion and exclusion criteria, 79 articles were retained for further analysis. There is a broad range of journals publishing this work, with the *Journal of Cleaner Production*, *Sustainability*, *International Journal of Production Research*, *Business Strategy and the Environment*, and *Resource Conservation and Recycling* having published the bulk of the relevant articles in this field. A recent literature review was conducted by Rejeb et al. [33] on the intersection of the IoT and the CE. The countries represented by these studies included UK 29, India 26, China 19, France 17, Brazil 10, Germany 9, South Africa 7, Australia 7, and USA 32 [33]. Our findings build on prior literature review studies discovering positive relationships between the CE and I4 [29]. Initial findings include CE environmental management practices in manufacturing firms that have gained popularity in remanufacturing and reusing products. Several studies include the conceptualization of the CE (Kirchherr et al. [34]), expected transitional impacts on ecosystems (Ghisellini et al. [4]), and the CE for product design (Mestre and Cooper [35]). Next is a review of the synthesis of the relevant literature.

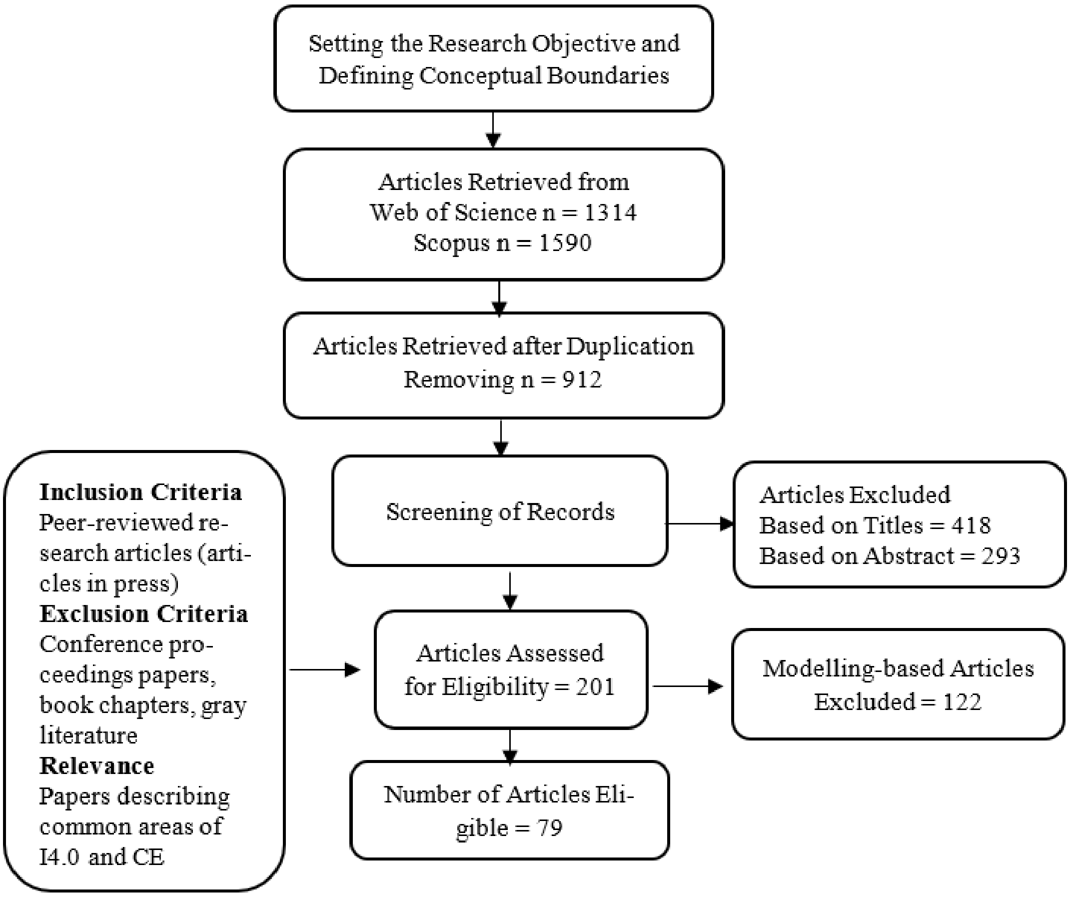

Figure 1. Article selection process.

3. State of the Literature

The review of the I4.0 and CE literature uncovered numerous avenues for scholars to explore in the future at the intersection of these phenomena and the integration of sustainability across business functions and value chains. The internal value chain (Porter [36]) and the global value chain (Gereffi (1999) and Staritz et al. [37,38]) provide insights as to the scale and scope of this field of research. These insights help us understand the strategic advantage of a CE and will also help inform the development of external and internal processes. The value chain uncovers how internal processes interact with external enterprises. At the core of the value chain concept is the "value system". Research on the value chain improves our understanding of how firms build production systems and their links to global economies.

The global value chain is vast and dynamic, yet can be consolidated into four elements, (1) "input–output structure", (2) "regionality", (3) "governance structure", and (4) "institutional framework" [39]. Through influencing primary activities, the value chain offers a functional perspective on how firms can internalize resources and activities to make intra- and inter-firm relationships more successfully than firms with a less extensive value chain focus. The current value chain literature implies that benefits arise from the value chain activities that include integrating key actors, increasing interaction, and collaborations with external partners and other non-value chain actors.

There is a need to consider the value chain from two perspectives. First, some firms manufacture semi-finished products and sell them to other companies to integrate them into other products. These intermediate products contain value-added processes. Due to the differences in products in the value chain, there is also a need to understand what constitutes good production strategies for the manufacturers up and down the supply chain [40]. Because of the difference in each industry's value creation process, the original equipment manufacturer is mainly responsible for value-added activities, such as research, design, and collaboration. Despite the focus on the value chain (Galvão et al. [13]), the literature has overlooked the impacts of the CE on manufacturers.

Knowing the CE is "the set of organizational planning processes for creating, delivering products, components, and materials at their highest utility for customers and society through effective and efficient utilization of ecosystem, economic, and product cycles by closing loops for all the related resource flows" [3] (p. 859), there are opportunities for more work uncovering the CE's impact on value chains. The literature on the value stream by Galvão [13] suggests little understanding of the value chain's theoretical and analytical levels. There has been limited evidence on "how" and "when" firms internalize value chain activities to implement new circular business models (Galvão [13]). The primary activities, i.e., (1) inbound logistics, (2) operations, (3) outbound logistics, along with (4) marketing and sales, and (5) services, provide further opportunities for synthesis of the literature, and future opportunities for research. Supporting these primary activities, Porter [36] outlines how value chains focus on different internal resources and activities that shape conditions to create and capture value in the existing business models. These integration activities consist of a full range of supporting activities, such as (1) firm infrastructure, (2) technological development, (3) human resources management, and (4) procurement.

3.1. Managing Primary Activities

3.1.1. Inbound and Outbound Logistics Capabilities

Critical challenges in the supply chain supporting CE transformation are inbound logistics and planning decisions, the demand for materials, and managing multiple network actors. As a result, Jagtap et al. [41] noted that more research needs to be conducted on the issues logistics 4.0 companies face when trying to use digital communication technologies in their operations. Inbound logistics is an industrial setting from suppliers to firms, including material handling, transportation, warehousing, and inventory management from supplier to production and assembly units or retail [42]. Therefore, coordinated inbound and outbound logistics activities and their sustainability are vital aspects of the value chain. Outbound logistics is an industrial setting from the firm to a customer, with procurement guided by the customer while enabling value creation [42].

The majority of the studies examine product design focusing on design capabilities. For instance, design thinking can be used as a strategy to achieve innovation; this approach to design can provide an opportunity to develop products that expand the sense of attachment and responsibility to nature and human beings [43]. Research to date has identified complexities and uncertainties associated with the reuse, remanufacturing, and recycling of materials. The literature calls attention to the growing importance of managing resource efficiency using closed-loop principles. Further, automation of the procurement process can reduce procurement uncertainties and improve resource usage [44,45]. Here, digitization helps to optimize the development of procurement, transportation, and inventory management, while also enabling CE transformations. Our insights from the literature suggest that the majority of inbound logistics articles have focused on investigating digitization's impacts on CE performance. Future research studies should investigate the effect of digitization on inbound, outbound, and reverse logistics efficiency and how this enables the transformation to circular business models.

3.1.2. Marketing, Sales, and Services

Here, studies examine the potential of remanufactured product sales (Guide and Li [46]), pricing decisions (Gan et al. [47]), warranties (Liao [48]), and marketing issues [49], reconfiguration of channel structure [50], and consumer motives on purchasing remanufactured products [51]. Understanding consumer demand and firm response to green products help build knowledge related to refurbished, recycled, and remanufactured products in the CE literature [52,53]. Yet, there is a lack of understanding in consumer emotional, cognitive, and innate mental models and calls for further investigation. CE performance influences the policies and procedures related to the design for remanufacturing, distribution, collection, and management of end-of-life products to recover value [49,54].

It is evident from the CE literature that marketing and sales strategies affect CE performance. However, the marketing and sales aspects of the CE in the domain of I4.0 have escaped scrutiny. Several studies have investigated consumer markets and consumer behaviors towards recycling products [55]. However, marketing and sales lack empirical studies, providing an immediate opportunity for further investigation. This includes studies examining consumer behavior and attitudes towards remanufactured, recycling, repaired, and refurbished products. Another avenue offering opportunities to study includes but is not limited to non-marketing stakeholders' role in promoting a sharing economy, how consumer behavior data affects managerial actions, and firm outcomes [56].

Sharing economy studies have emerged in the marketing literature (Eckhardt et al. and Dellaert [57,58]), and refer to "buyers dealing with different products and/or service providers for each transaction" [56]. Due to growing interest in the sharing economy, a technologically enabled sharing ecosystem can help explain emerging changes in digital and traditional marketing [59]. Scholars should investigate the effects of internal stakeholders, e.g., firm decision-makers' thought processes, when developing a CE strategy. Studying the implications for CE performance relative to the competition could help advance the field. Recent research studies have used mathematical and linear integer modeling to examine at the firm level a circular business model's strategic management. This leads us to recommend further investigation into how industry characteristics interact with the design and implementation of marketing and sales activities to influence short- and long-term CE performance. Studies on marketing and sales have generated novel insights into how organizations change internal processes to support the CE. There is an increase in the applications of I4.0 in different value chain activities to meet customers' expectations [60]. Lieder and Rashid [61] and Pieroni et al. [62] highlight a theoretical and practical research gap and recommend avenues to enhance the value chain. Given the importance of providing stakeholders with greater value and meeting their increasing expectations, it is important to further examine marketing, sales, and services with the following sample research questions and primary activities summarized in Table 2.

Table 2. Future research integration opportunities in value chain primary activities.

Key Themes	Future Research Opportunities
Inbound and Outbound Logistics Capabilities	* To what extent do disruptive trends in digital manufacturing (e.g., designing modular vehicles for simultaneous delivery and collection of goods) influence production efficiency, and GHG emissions compared to alternative production methods? * What is the effect of advanced manufacturing process technologies on the value of circular business models? * How will vehicle automation technology influence warehousing and reverse logistic management?
Marketing	* How does organizational marketing (i.e., saving material costs, reducing production costs, minimizing emissions) moderate the relationship between brand equity and green product design?
Sales and Services	* How do social media platforms, online advertising and sales promotion tools affect the recognition of a remanufacturer's brand and satisfaction, and provide reputational benefits? * How does a digitized product service system affect customer and consumer decision-making?

3.2. Managing Value Chain Supporting Activities

Supporting activities represent the organizational framework within infrastructure, technological development, human resource management (HRM), and procurement. These activities support and enhance the organization's primary and strategic governance of its value chain. Strategic governance is concerned with managing the firm's boundaries, internal transactions, and external interface governance [63] (p. 6). See Appendix A for a summary of the primary studies focused on I4.0 and value chain activities.

3.2.1. Infrastructure Development

Transitioning to a CE involves a different but interrelated network or partner activities for reorganizing and streamlining the materials flow. The research on the determinants of infrastructure development, the consequences for recyclability, and extended product life cycles are underdeveloped. A transition towards a CE for manufacturing firms will include upgrading and developing technology infrastructure. This infrastructure includes: selecting artificial intelligence in designing and selecting efficient material, increasing resource efficiency, predictive maintenance through machine learning approaches, and extending the end of product life through intelligent manufacturing tools [64]. Changing and upgrading the existing infrastructure in reuse, refurbishment, remanufacturing, and reverse logistic networks will help increase the life of materials driving the circular economy. The CE can reduce the production and consumption of materials, promote material resilience, enable closed-loop systems, and help optimize ecological systems [65]. Here, I4.0 is vital in moving firms forward with technological innovation as an enabler of change [60].

The literature suggests that local and global firms can upgrade firm infrastructure by combining intelligent computational tools and analytics to interpret, collect, sort, separate, and redistribute the material for remanufacturing and refurbishment. I4.0 intersects with a CE as firm infrastructure, and technology support activities are crucial to moving a firm toward evolving circular business models. This evolution can ultimately contribute to the CE, enabling the design of new business models and increasing the likelihood of value preservation [66].

Future research should examine the dynamic capabilities that mediate the relationship between infrastructure planning and CE initiatives' support. For example, there is a need to identify the impact of developed infrastructure on transforming existing business models into circular business models. Infrastructure does impact not only primary activities but also other supporting activities. The literature suggests that skills for transforming technology within an organization to create new circular business models are in high demand, and human resource management should consider these emerging needs. Further, De los Rios et al. [67] point out that human skills determine the valuable decisions to shift towards CE solutions.

Additionally, external collaboration is linked to the development of internal capabilities development when creating products and services for a successful and more sustainable business model. This sustainable model resides in how firms successfully adapt to the demands of the changing business environment. Future research can and should benefit from an in-depth consideration of different stakeholders' demands on infrastructure and technology development to enable the shift toward circular business models.

3.2.2. Human Resource Management

Studies in this domain highlighted human resource management's vital role in organizational environmental goals, green innovation, low carbon management, and green training initiatives [68]. HRM influences a firm's ability to achieve organizational-level sustainability (Jabbour et al. [5]) and I4.0 circular business models are emergent phenomena.

Value creation exists not merely because of the application and utilization of big data tools (Nascimento et al. [15]), but rather because individuals in the organizations share common beliefs and norms. Prior research suggests that social capital is essential in everyday task performance in manufacturing, planning, and control, as digital technology helps in optimizing resource usage and lessens the impact on the natural environment [69]. The literature review highlights the need for I4.0 and CE scholars to move beyond training and employee empowerment initiatives and consider individual personality characteristics as enablers of CE initiatives. There is a need to explore the impact of individual technology and learning orientations in shaping individual actions toward CE initiatives. There is strong evidence that little is known about how various human resource management characteristics lead to circular business models within the I4.0 environment. Further studies can depart from the traditional development of job responsibilities by examining the organizational design of circular initiatives and business models.

There is evidence that human resources can advance CE initiatives at the organizational level by developing reuse, repair, product upgrade, and capacity sharing policies. Jabbour et al. [70] found that CE initiatives from human resource management led to more pro-environmental initiatives among employees. These initiatives also led to the successful implementation of circular business models for closed-loop production and consumption [71,72]. However, these HRM aspects have not been fully considered or studied as factors influencing I4.0 and circular business model design.

Within the context of HRM, there are opportunities for further research to investigate this and other management characteristics within organizations, along with identifying personality traits impacting CE initiatives to close material loops. Here, future research studies should examine the relationship between individuals and their resulting influence on overcoming barriers to implementing circular business model initiatives at the organizational level.

3.2.3. Technology Development

Research suggests that information and communication technology enable circular business models by adopting new technology. Rice and Martin [73] posit that information and communication technologies provide the capability to design and manage critical infrastructure. Given the importance of technology, firms can empower CE initiatives through smart maintenance, reuse, manufacturing, and recycling [74]. Researchers have examined the relationship between technology adoption, partner selection, and value creation. Future research can enhance our understanding of how firms can expand their virtual manufacturing to produce a product with new I4.0 standards [15].

Identification of various I4.0 technologies influencing smart manufacturing activities and technologies should be implemented in product life cycle management [75]. The literature reveals that the IoT, industrial internet, information networks, cloud computing, big data analytics, cyber–physical systems, and software systems have provided many benefits. Examples include but are not limited to enabling high flexibility, clock speed change in order delivery and product development, and rapid transferring of customer demands into the production process for value creation [76]. Other examples are flexible and agile manufacturing processes and improved decision-making (Tachizawa et al. [77]), enabling a proactive approach towards information sharing and problem-solving (Shamsuzzoha et al. [78]), and continuous resource optimization and effective automation process in manufacturing [75].

Emerging IoT, industrial internet, and big data analytics technology can help the transition from a linear economy to a CE by aiding circular products and components design and optimizing infrastructure to ensure circular product and material flows [66] (p. 12). Therefore, scholars should consider studying the extent of infrastructure development and how it enhances the transition to a CE with opportunities to measure short-term and long-term CE performance indicators.

3.2.4. Procurement

Technologies used by manufacturers in procurement can enhance eco-effectiveness and eco-efficiency [79]. These CE practices and policies positively impact organizational development and the transformation toward CE business models. Automation of the procurement process can significantly reduce procurement cycle time and optimize resource usage [80]. This can be done with innovative technologies such as radio-frequency identification, tags and sensors, global positioning systems, smart mobile devices, shelf-moving robots, and automated guided vehicles [80]. This is especially applicable to uninterrupted logistics/information flow and transparency, as precursors of the CE transformation [61,81].

The gaps identified in understanding how emerging technologies empower decision-makers in procurement are opportunities for future work [60]. In addition, future research should define the consequences of automation and procurement in I4.0 by integrating analytics capability across the supply chain to help close material loops for the CE. Finally, scholars can further examine the procurement process and the other supporting activities in I4.0 with the following guiding research opportunities summarized in Table 3.

Table 3. Future research integration opportunities in value chain supporting activities.

Key Themes	Future Research Opportunities
Infrastructure Development	* Can the local or global collaborative network relationships be differentiated based on systems that need closed-loop products and materials coming back into the economy? * How do CEs and I4.0 enable value chain activities? * To what extent do I4.0 infrastructure investments support resource efficiency, the CE, and the emergence of disruptive business models?
Human Resource Management (HRM)	* What is the relationship between organizational human capital development and CE performance? * Where and how can HRM utilize I4.0 to support CE business models? * How do management policies for more sustainable resource use, consumption, and production create opportunities for collaboration, product design, the promotion of local sourcing, and green initiatives?
Technology Development	* What is the relationship between I4.0 technologies (sensors and detecting devices) in building business capabilities to expand CE business models? * What practices are best to identify emerging technologies supporting value chain activities? * How do I4.0 technologies facilitate the identification of network partners for different manufacturing models (i.e., make to order vs. assemble to stock)?
Procurement	* To what extent do digital technologies in procurement impact the organization's supplier selection process and new product development process? * How does I4.0 enable the strategic alignment of procurement in a product's life cycle and CE? * To what extent does I4.0 increase procurement's information processing capacity to help optimize processes in the CE?

4. Contributions

The manufacturing industry is changing from a linear (take–make–use–dispose) model to a circular economy. In addition, the value chain, as a set of primary and supporting activities necessary to deliver a valuable product to market, is impacted by the technological innovation of I4.0. Our review of the literature suggests that the transition to a CE and examining value chains enabling this transition will be fertile ground for future research. This study demonstrates how I4.0 and the CE contribute to the value chain while focusing on manufacturers and providing new opportunities for future research.

Porter's value chain model breaks operations into strategically essential activities and identifies opportunities for competitive advantage with categories of value-creating activities [36]. This value creation and the outcomes of this study call for evaluating applicable I4.0 and CE business model dimensions. The evolving digital transformation enables the operational dimension while performing activities effectively and efficiently to create customer value. A firm must create processes to control and manage the activities associated with its operation and other supporting activities to provide value to its customers and sustain business operations in the emerging I4.0 and CE of the future. This dimension focuses on how a firm conducts its business, what products or services it offers to its chosen customer group, and how it will produce and deliver products or services. These processes and controls can also align with goals for global sustainability as opportunities for further integration across business functions to reduce greenhouse gas emissions [82].

It can be argued that considering the intersection of I4.0 with the CE allows redesigning existing business models to include innovations that can lead to strategic actions aligned with sustainable development. Our study expands on [36] to discuss the value chain by adding I4.0 and CE contexts. Yet, more will need to be done to understand why and how firms survive industry transformations. Therefore, it will be necessary for researchers to explain and predict how organizations with different business models will affect each other in the changing I4.0 and CE. For example, production line data are used in other areas, such as procurement planning, pricing, marketing, warehousing, and by managers of logistics. Different functional areas such as research and development, controlling, and quality assurance also utilize these data for greater accuracy, process automation, real-time analysis and reporting. Technological innovations and resulting data can lead to the increased integrated management of environmental and social performance [12,20].

This study provides contributions to the literature. First, the dynamic dimensions of business models must be considered a departure from the traditional operational models. The dynamic model represents organizations that adapt to changes and continuously align their activities to the ecosystem in which they operate. Next, the current I4.0 and CE literature is mainly internally focused on operations in the supply chain, lean manufacturing, and supplier selection domains. Digital transformations, such as those at the heart of I4.0, will be embedded in the value chain activities to drive emission reductions, economic growth, innovation, and competitive advantage.

Several factors contribute to a more rapid digital transformation strategy and new business models. However, much of the prior research focused on how to implement the latest technologies to innovate the business model. Figure 2 displays the I4.0-enabled digital transformation and its impact on the potentially CE-based dynamic business model.

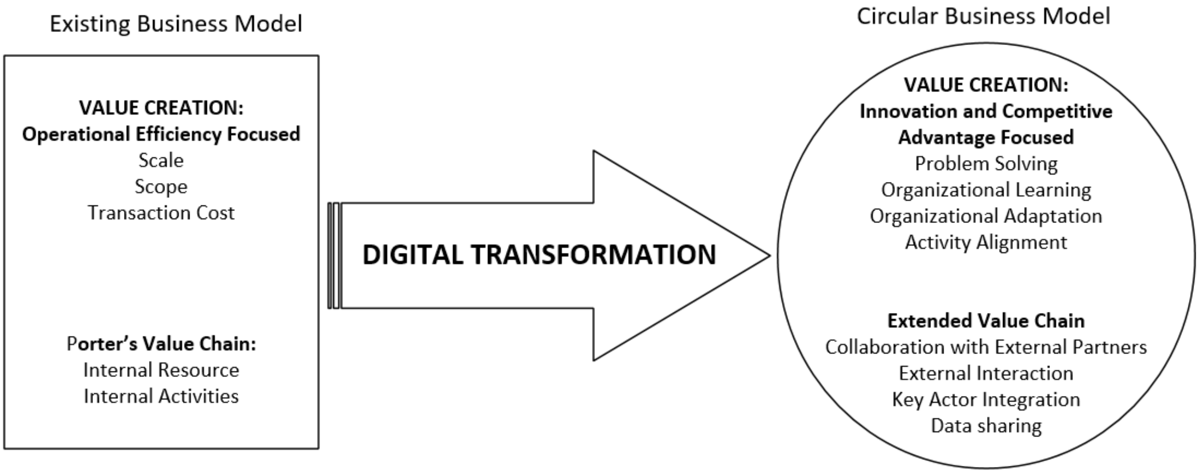

Figure 2. The impact of digital transformation on business model integration.

Second, much of the research focuses on the impact of I4.0 on the CE [15]. Little is known about the influence that I4.0 and the CE have on value chain activities for manufacturers. Several scholars have suggested that the supply chain may benefit from

I4.0 and CE activities [83], and [84] provides evidence that I4.0 technologies can enable sustainable manufacturing (reducing pollution and resource waste). However, less attention has been given to examining how I4.0 and the CE influence value chain activities. Literature reviews such as this one provide a structured approach to understanding this evolving field of research. Our analysis enables us to assess the influence of the value chain on the CE, thus revealing various research gaps and offering opportunities for future research. Our review shows dynamic relationships between I4.0 and the CE. The literature review in this study adds to a growing understanding of the field of research by showing that engaging with I4.0 and the CE is desirable and necessary for internalizing knowledge flows across different value chain actors.

Third, our literature review diverges from the previous studies in the domain of I4.0 and the CE. It shows how value chain activities can support CE initiatives in digital manufacturing planning and material traceability control. In this way, Bueno et al. [85] suggest that digital transformation affects the decentralization control, mass customization, and real-time traceability of parts and components. Expectations include seeing more research expanding on this continued digital transformation. Our literature review also contrasts with prior literature review studies that focus on a supply chain context (Bressanelli et al. [86]), IoT-enabled CE business models [74], or sustainable manufacturing and I4.0 [84]. The outcomes of this study help to explain how value chain activities relate to contemporary I4.0 and CE practices. With a focus on how I4.0 is driving the circular economy at the value chain level, the findings show that technologies assessed in this study span functional boundaries and affect the value-creating process in new, dynamic ways. Our review provides future research insights into the value chain in the manufacturing industry context. Previous scholars have called for literature review studies specific to the supply chain perspective [6]. More work remains to understand how circular business models generate and enable value in different parts of a circular supply chain [87]. The global manufacturing industry is affected by uncertain technology disruption, which will continue. This study is a step in the right direction in developing and understanding the critical role of value chains and evolving business models in a global economy.

5. Conclusions

Our findings highlight the importance of considering the impact I4.0 and the CE have on value chain activities, and how they impact existing business models, drive innovation, and enable value creation. Building on Porter's value chain structure, the primary and supporting activities reveal that I4.0 affects production and other organizational areas when transitioning to a CE. In addition, digital transformation is a catalyst for developing new business models and future research.

This study reviews and summarizes the I4.0 and CE literature using a systematic literature review methodology from a value chain perspective. This work aims to organize significant findings, uncover key research areas, assess the role of value chains, and develop future research opportunities. Our review shows how and why research can be conceptualized around value chains and that this value should include sustainable development. There are distinct extant perspectives on the value chain and numerous future research opportunities. There has been much interest in researching the interface of I4.0 and the CE in recent years, as seen in the abundance of relevant scholarly works. While the literature on I4.0 and the CE continues to emerge, it has developed along fragmented and narrow disciplinary fields. A theoretical contribution of the current study is the conceptual framework that integrates I4.0 with CE deployment to achieve long-term objectives while also addressing value chain challenges.

A limitation of this study stems from the challenge of gathering related articles from the Web of Science and Scopus databases. Subsequent studies will need to look for additional data sources, such as IEEE explore and ACM databases, to broaden the applicability of the research in various fields. A further limitation of this review involves using a limited set of keywords. Future research studies will be necessary to expand the relevant keywords to retrieve more records and identify industry-based technologies and CE initiatives. Additionally, the focus of this study was not to map prior scholarly work to see how it aligns with the UN SDGs. Instead, we see this mapping exercise as an opportunity for future work as the I4.0 and CE phenomena evolve. Despite these limitations, this review of the literature contributes to scholarly research by providing several future research opportunities. This study identifies and covers a diverse array of empirical developments in the field. Identifying the relevant research topics and how I4.0 and the CE have evolved in the value chain help to broaden our understanding of these developments.

There has been a significant increase in interest among scholars in the phenomenon of I4.0 and the CE in recent years. Yet many theoretically and empirically relevant issues have not yet been developed from a value chain perspective. The growing interest in the digitally-enabled CE calls for more efforts to address how value chains transform industries, economies, and sustainable development. This study presents a novel framework to help demonstrate I4.0's critical role in CE implementation. This framework illustrates the importance of how I4.0 and the CE may help transform existing business models into new circular business models enabled by value chains. Practitioners can use this digital transformation business model to help them recognize and develop change management initiatives for transition towards an I4.0 integrated CE business model. Therefore, scholars can frame these two phenomena as complements while also looking for emerging relationships with goals for sustainable development. Further exploration of drivers, enablers, relationships, and performance metrics related to value chain support activities will be needed in the future.

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Appendix A. Studies Focused on Industry 4.0 and Value Chain Activities

Author(s)	Key Findings
[19]	A better understanding of government, suppliers, international organizational interests, and expectations around the IoT is necessary for the transition to Industry 4.0's circular economy.
[88]	It has been shown that the implementation of CP and the CE and making a solid contribution to sustainability is made easier through Industry 4.0.
[89]	Even though modern technology provides new and innovative solutions to the CE, scholars do not seem to be using it.
[90]	It is suggested that numerous issues are hindering the implementation of the I4.0–CE model, including the lack of government support and incentives and the lack of policies and protocols.
[91]	Based on research findings, it appears that the key resources needed for implementing Industry 4.0 are manufacturing systems, human resources, project management, leadership, green logistics, design, information technology, big data analytics, and collaborative relationships.
[92]	The infrastructure development decision is strongly affected by market conditions and uncertainty. This study highlights the link between business analytics and closed-loop control strategy. Determine how to utilize intelligent manufacturing in network relationships. Deployment of new IT infrastructure is much needed. Examine the effects of human–machine interactions in facilitation of CE practices from the perspective of I4.0.

Author(s)	Key Findings
[93]	Firm-level capabilities simultaneously affect the competitive position and management of presales, after-sales services, and product delivery in a short period. The authors also discuss the new challenges firms face in developing new business models, applying I4.0 associated technologies to achieve greater flexibility and improvement in product design, and leadership in pricing strategies.
[94]	The core hypothesis of the study is that the adoption of I4.0 improves sustainability dimensions. How investment decisions in technology influence social and environmentally sustainable development. The new forms of technology can best support the value chain activities and control mechanisms to support production in a resource-efficient way.
[95]	The involvement of multiple stakeholders is important for designing circular strategies to create value for customers. The design for the circular product–service system is at the initial stage. It often depends on value chain activities and, as a result, has to understand multiple stakeholder needs and expectations.
[13]	Investment in infrastructure and government support is a key enabler of circular business models.
[96]	Operational flexibility and efficiency are positively associated with developing the I4.0 strategy. There is a need to understand how political and legal boundaries, cooperation and collaboration, and state-of-the-art open and flexible IT infrastructure affect a wider broadband deployment within the region. The presence of I4.0 might have a negative impact on human health and safety issues. Do domestic laws support firms in implementing I4.0 associated technologies.
[97]	Challenges found related to data quality and management and development of IoT enable circular economy strategies.
[98]	I4.0 associated technologies positively support flexibility, integration, and real-time prediction of quality issues to achieve all organizational performance. Identifies ten organizational performance measures and consequences for creating a learning environment and managing a performance-oriented manufacturing system.
[99]	The impact of business analytics is greater on the circular economy for manufacturing firms. A more complex issue in the value chain is "sustainable consumption", which requires greater attention, and is more likely to govern BDA capabilities to extract finite and virgin resources. Along with production, the full extent of circular economy performance is expected to determine whether BDA capabilities foster efficiency and productivity.
[100]	"CPS, one of the main elements of Industry 4.0, incorporates specific technologies and characteristics and can be applied in several areas of society, including health, mobility, production and logistics" (p. 11).
[101]	The study emphasized that decentralization and networking building with different actors bring more opportunities for sustainable manufacturing. Consider various life cycle management approaches for design and maintenance. This study also highlighted the impact of cleaner production, big data, social manufacturing relationships with industrial symbiosis, collaboration, and logistics 4.0 for a circular economy.
[102]	This study has emphasized the importance of establishing strategic management for technology deployment. In this study, attention is devoted to the degree of institutional involvement.
[103]	I4.0 associated technologies are critical for lean manufacturing and highlight the supply chain partners' capacity for technical support and development of human resource management. There is also a need for institutional, regional, and national level support to develop platforms for moving forward towards inbound logistic management.
[29]	"Adopting the circular I4.0 perspective, managers can choose their CE targets, and according to them, identify the set of I4.0 technologies that best support the managers' strategy. Authors confirm that I4.0 technologies positively effect the life cycle management of products" (pp. 1678–1679).
[104]	Involvement of customers in the design and manufacturing process, and increased proximity geographically. The authors identify factors that can affect the implementation of I4.0 over the value chain: (1) "transform the organization to the required degree of change as a result of industry"; (2) "cross-functional management control capabilities"; (3) "build a service-centered alternative to the traditional goods-dominant (G-D) paradigm for understanding economic exchange and value creation"; (4) "Industry 4.0 is dependent on the extent of digitization and flexibility of the supply chain"; and (5) "creating the proper culture and necessary alliances within the organization".
[105]	The significance of I4.0 in manufacturing is well documented. Recent advancements in technological innovation revolve around addressing barriers and challenges of the Industry 4.0 revolution. Firms operating in developing countries could take more advantage to pursue infrastructure development, focus on employee training with digital tools, upgrade skills, and develop close operations with different stakeholders. Examining the influence of investment allows the company to develop infrastructure.

Author(s)	Key Findings
[106]	Highlights the importance of understanding HRM for improving human–machine interaction for effective product life cycle management. The authors develop a framework for value chain activities and suggest enablers for effective supplier commitment, sustainable procurement, digitalization of supply chain activities, and tracking real-time supplier activities. The authors highlight the adoption of cyber–physical systems, flexible manufacturing, continuous material reduction, information sharing, and reverse logistics networks.
[107]	Discusses the potential implication of digital twins in "human–machine collaboration", "sustainable smart manufacturing", and "sustainable product life cycle management".
[108]	Firms that implement I4.0 are more likely to upgrade flexibility and agile manufacturing and effectively reduce material costs. PLC, acquisition of raw material from suppliers, reusing, remanufacturing, recovery, recycling, and management of the logistics, should be based on vertical and horizontal integrations. "Simulation technology in I4.0, using VR, is an integral process to simulate all industrial processes (p. 916)".
[109]	The study results suggest that industrial partners must develop an IoT business model, find and develop flexible structures across geographically dispersed customers, and develop omni distribution channels with the support of I4.0 associated technologies.
[110]	First, developing more service-oriented products and improving the internal engineering process can gain more value from external customers. Increase the level of product service offering resulting in the establishment of competitive advantage.
[111]	Digital cooperation and integration function as options to expand the exploration of knowledge regarding the new procurement dynamics. Firms are more likely to focus on developing new organizational cultural practices, managing institutions and regulations, and increasing communication using new digital tools of Industry 4.0.
[112]	Manufacturing firms need to focus on end-of-life cycle management to facilitate eco-design and life cycle management practices in I4.0. These include I4.0 associated technologies to manage the product life cycle. A strong relationship is observed in upgrading technological infrastructure and improvement in end-of-life products.
[113]	This study informs that I4.0 facilitates management functions. The rise of I4.0 practices provides more opportunities to reorganize value chain activities, such as technological integrations, organizational restructuring, and human resource practices. Manufacturing firms need to develop technological capabilities to manage value chain activities.
[5]	Firms focus on big data analytics, strong collaborative capabilities, and especially assistance support from the government for economic performance and development of circular business models.
[6]	This study highlights the importance of management strategy towards information retrieval, sharing product management data with different stakeholders, improving material efficiency, and using environmentally friendly materials for green and improved manufacturing process.
[114]	The author highlights some of the main challenges of value chain analysis and discusses the existing partner relationships and competencies needed to support sales activities, technology, and product innovation capabilities for designing new business models. He suggests that companies design capabilities for the marketing product service system, integrating and mobilizing blended digital strategies to create value using IoT platforms and linking to create and capture value.
[115]	Creating new service design and focusing on human resource development to support I4.0 initiatives to drive organizational changes for autonomous operations and increase innovation performance.
[116]	Digitalization infrastructure upgrading acts as a bridge between the circular economy to help firms reduce waste and add value to the process.
[117]	Manufacturing firms operating in I4.0 need to develop individual levels of human–machine interaction, particularly in production. This study highlights that I4.0 associated technology and the integration of humans in manufacturing are important. It can also support ongoing firm economic performance.
[118]	Marketing activities are likely to enhance consumer trust in remanufacturing products. Price considerations of upcycling products with high variety and quality are important factors enhancing consumer trust. In addition, joint funding cooperation can create initial collaborative business ties.
[119]	Smart transportation encourages material delivery with efficiency and enables logistics to create value.
[8]	Industrial symbiosis is key to achieving performance using data-driven insights on reducing, reusing, and recycling materials.
[120]	Firms with big data analytics applications have potential opportunities with the value of growth opportunities.

Author(s)	Key Findings
[121]	When it comes to the digital and automated manufacturing environment, Industry 4.0 and its other synonyms such as smart manufacturing, smart production, and the IoT have been identified as major contributors.
[122]	To increase their competitive position, firms require investment in infrastructure (technical infrastructure). Organizational transformation plays a crucial role in accumulating more resources.
[123]	The value creation process often starts with the application and use of digital tools. Digitization capabilities are more important than conventional capabilities.
[124]	Manufacturers that center on technology development have increased operational reliability—contracting on maintenance agreements and parts of service influence the level of a close relationship.
[125]	At the center of servitization companies can exploit the reverse and forward supply chain. Therefore, IoT generates positive benefits and permits to development of comprehensive product biographies.
[126]	The product–service system requires supplier–customer relationships that develop new business models, internal organizational structure, and customer management about improving the repair, maintenance, product, and process upgrade are beneficial for suppliers.
[127]	Low formalization contracts for product and service design play a complementary role in transforming business models and influencing consumer attitudes.
[128]	Manufacturers can gain circular economy performance with greater flexibility in contracting. Provide infrastructure support for service delivery networks and key partners.
[129]	Governments and businesses agree to develop standards with a greater level of explicit cooperation.

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