Chapter 4
Supply Chain 4.0 to Enhance Circular Economy

L. Davila, J. Mula, and R. Sanchis

Abstract The main theme of this literature review is supply chain (SC) models that focus on circular economy (EC), Industry 4.0 (I4.0) and green operations. Special interest is paid to optimisation models and intelligent and digitalised supply chains, whose operations are based on circular business models. This circularity approach allows resources to be reused to strike a balance between economic growth and environmental concerns. This literature review analyses the current research state according to: objectives and the context; research methodology and methods; benefits; limitations and critical points.

Keywords Supply chain · Circular economy · Green · Industry 4.0 · Optimisation

4.1 Introduction

Genovese et al. [13] distinguish between a green and sustainable supply chain (SC) and the economy circular (CE) concept. A green SC refers to the strategy of integrating environmental issues into manufacturing organisations by reducing material flows or minimising the negative consequences of production processes [31], i.e. a linear SC. The CE concept is related to production methods that are self-sustaining and true to nature, where materials are used over and over again [26]. Here Geissdoerfer et al. [12] consider sustainable development to be a broader and more intangible concept than CE, which could be converted into a more tangible way to organise the society and economy, and to define circular SC management as the configuration and

L. Davila · J. Mula (✉) · R. Sanchis
Research Centre on Production Management and Engineering (CIGIP), Universitat Politècnica de València, Alarcón, 1, 03801 Alcoy, Alicante, Spain
e-mail: fmula@cigip.upv.es

L. Davila
e-mail: luida@epsa.upv.es

R. Sanchis
e-mail: rsanchis@cigip.upv.es

C. Avilés-Palacios and M. Gutierrez (eds.), *Ensuring Sustainability*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-95967-8_4

coordination of organisational marketing tasks, sales, R&D, production, logistics, IT, finances and customer services within and between business units and organisations to minimise the system's input resources and loss of waste and emissions, improve its operational effectiveness and efficiency and create competitive advantages.

Simultaneously, digital technologies enable SC management in the current Industry 4.0 (I4.0) context to evolve [18]. In this context, Nascimento et al. [28] focused on sustainable SC management, additive manufacturing and smart production systems to address how I4.0 technologies can be integrated with CE practices. Daú et al. [9] simultaneously define sustainable SC and 4.0 as that which uses I4.0 tools to close materials and energy cycles and to help information and activities to flow. Manavalan and Jayakrishna [24] recommend using I4.0-related technology in the transition from a linear to a circular SC.

We herein present a summary of a more general review on SC 4.0 and on CE reviews, conceptual and analytical approaches. This review aims to act as a starting point for novel optimisation and simulation models for SC 4.0 according to CE criteria.

4.2 Review Methodology

The review methodology was based on exploring articles by employing mostly the Scopus scientific and technical database and the Web of Science to a lesser extent. No time restrictions were set. Articles were searched for and observed by combining several keywords, which were later selected in line with the selection criterion of these keywords. We now summarise the number of articles selected by searches based on these keywords: supply chain, circular economy, Industry 4.0: four results; supply chain, Industry 4.0: 13 results; supply chain, circular economy: 13 results; optimisation, supply chain, circular economy: two results; supply, chain, circular, economy: seven results; and Industry 4.0, supply chain, green, circular economy: one result with a total of 40 results.

The scientific sources of the selected articles are recognised in the research area. Table 4.1 presents the scientific sources from which 24 articles were taken.

4.3 Literature Review

We classify the reviewed works in terms of objectives and context, research methodology, benefits and limitations.

Table 4.1 Scientific source and selected references

Source	References
International Journal of Production Research	5
Sustainability	5
Journal of Cleaner Production	4
Procedia Manufacturing	3
Resources, Conservation and Recycling	3
Omega	2
Process Safety and Environmental Protection	2
Others	16

4.3.1 Objectives and the Application Context

Table 4.2 summarises the objectives and the application context of the reviewed papers.

Regarding the main objectives of the reviewed works, it is important to highlight the aim to integrate economic and environmental objectives into SC management [36]. Indeed the economic SCOR SC management model has been adopted to extend it towards circular SC practices [32]. Sustainability principles in SCs have also been addressed with optimisation models [27]. SC configurations according to sustainable [20] and circular principles have been analysed by several works [25, 30, 35], whereas the necessity for cooperation practices from consumers to suppliers has been studied [41, 42]. The government regulation to implement CE practices has been addressed [40, 42]. Several performance measurement systems or indicators have been proposed to evaluate circular SCs [16] to, for instance, compare linear and circular SC models [9, 12, 15, 24, 29].

On more ecological issues, direct, indirect and total life cycle emissions, waste recovered [17], virgin resources use, gas emissions [14] and carbon maps have been addressed by several works with circular principles [5, 13]. Finally, I4.0 technologies, such as IoT [4], optimisation algorithms, big data [34] and RFID [23], among others, have been applied to support digital SCs [2, 7, 18, 19, 33], logistics 4.0 [3, 37], sustainable SC management [1, 11, 22] and circular principles [10, 28, 38, 39].

According to the contexts to which the analysed papers apply, some works focus on automotive [5, 36], chemical and petrochemical, construction [7, 14, 29], electronic, food [13, 20], footwear and apparel [23], health care and mechanical, mobile [2], pharmaceutical [11] and steel [30] SCs. SCs, and global SCs in general, are also widely considered by several works [3, 18, 19, 32]. The interest shown in studies on I4.0 and logistics 4.0 has recently increased. Finally, it is important to highlight that the SC nationalities where case studies are conducted are basically Brazilian [9], Chinese [39–43,], European [30], Indian [7, 22, 24] with electronic and food [13, 20, 38] and Italian [17] and South African [1].

Table 4.2 Objectives and application context

References	Objectives	Context
Winkler and Kaluza [36]	To integrate economic and ecological objectives towards sustainability by creating networks of sustainable SCs and taking a circular approach	SC networks and automotive industry
Zhu et al. [41, 42]	To study how environmental SC cooperation practices influence CE and environmental and economic performance	Various Chinese sectors
Zhu et al. [43]	To examine the influence of international/national regulating politics on environmental management innovation on production operations	Chinese manufacturers
Schrödl and Simkin [32]	To integrate CE principles into the economic SCOR SC (SC operations reference) management model	SC management
Ivanov et al. [19]	To assign jobs to machines in a multistage flow shop scheduling problem	Flexible flow shop with alternative machines
Barreto et al. [3]	To deal with efficiency in organisations by using logistics 4.0	I4.0 and logistics 4.0
Butzer et al. [6]	To develop a performance measurement system for sustainable SCs	International reverse SCs
Genovese et al. [13]	To compare the performances of traditional and circular production using: direct, indirect and total life cycle emissions, waste recovered, virgin resources use and carbon maps	Chemical and food industries
Ghani et al. [14]	To focus on tracing greenhouse gas (GHG) emissions across the building SC industries and provide an optimised GHG reduction policy plans for sustainable development	SCs of building structures

(continued)

Table 4.2 (continued)

References	Objectives	Context
Majeed and Rupasinghe [23]	To improve inbound and outbound operations in an enterprise resource planning (ERP) system by using radio frequency identification (RFID) technology and business application programming interface technology in SAP®	Apparel and footwear industries
Masi et al. [25]	To identify the goals and assumptions about CE at the meso-level and assess the state of the art on CE SC configurations	SC configurations
Nasir et al. [29]	To assess and compare the environmental impacts associated with circular SCs to those related to traditionally manufactured products (linear SCs)	Construction SCs
Tjahjono et al. [33]	To analyse the impact of I4.0 on SCs on the whole, particularly on procurement, transport logistics, warehouse and order fulfilment	SC 4.0
Witkowski [37]	To present smart solutions to improve firms' competitiveness using I40 tools in logistics	Logistics and I4.0
Zeng et al. [40]	To test the mechanism and relations among institutional pressure, SC relationship management, sustainable SC design and CE capability	Chinese eco-industrial park firms
Bag et al. [1]	To identify the I4.0 enablers of SC sustainability and further attempt to propose a research framework that bridges theoretical gaps	South African manufacturing sector
Barata et al. [2]	To identify avenues for future research into mobile SC management in the advent of I4.0	Mobile SC

(continued)

Table 4.2 (continued)

References	Objectives	Context
Braun et al. [5]	To assess material efficiency within company borders in the SC by measuring the material demand and the amount of waste materials both with and without CE aspects	Manufacturer of surface-coated automotive parts
Dallasega et al. [7]	To introduce the proximity theory and deal with the impact of I4.0 concepts in SCs	Construction SCs
Ding [11]	To identify the sustainability barriers of pharmaceutical SCs and investigate how I4.0 can be applied to sustainable SC paradigms	Pharmaceutical SCs
Geissdoerfer et al. [12]	To propose a conceptual framework to circulate business models and SCs	Business models and SCs
Govindan and Hasanagic [15]	To identify the main drivers, practices and barriers to implement CE	SC management
Ivanov et al. [18]	To discuss and develop a framework for SC digital technology and disruption risk effects	SC management
Lopes de Sousa Jabbour et al. [21]	To develop a roadmap to improve the application of CE principles by I4.0 approaches	CE and I4.0
Luthraa and Mangla [22]	To identify, analyse and prioritise challenges for I4.0 initiatives to be efficient for the sustainability of SCs in emerging economies	Indian SCs
Tseng et al. [34]	To present CE and big data as a solution to optimise industrial symbiosis practices	I4.0
Yang et al. [39]	To explore the relation between the business model innovation of product-service systems and circularity in SCs	Multi-business manufacturing company
Bendaya et al. [4]	To summarise the role and the impact of the Internet of Things (IoT) on the main SC processes	SC management

(continued)

Table 4.2 (continued)

References	Objectives	Context
Daú et al. [9]	To analyse sustainable health 4.0 SCs by means of the conceptual framework of CE transition mirrored by CSR	Brazilian healthcare SC
Howard et al. [16]	To present a framework for developing CE indicators	Global companies
Isernia et al. [17]	To evaluate the extent to which waste electrical/electronic equipment management is able to meet the targets defined by the European Union (EU) by focusing on the collection centres that are the initial point of the reverse logistic cycle	Italian companies
Manavalan and Jayakrishna [24]	To analyse a case example in an SC organisation to meet I4.0 requirements and to enable CE	Indian paper manufacturer
Muñoz-Torres et al. [27]	To propose an assessment framework that extends sustainability principles to other SC members	SC management
Nascimento et al. [28]	To explore how the technologies arising from I4.0 can be integrated with CE practices	Manufacturing
Dev et al. [10]	To propose a roadmap for the excellence of operations for sustainable reverse SC/logistics by the joint implementation of I4.0 principles and CE approaches	Refrigerator company
Van Engeland et al. [35]	To provide an overview of strategic network design in waste reverse SCs by means of combinatorial optimisation models	Waste management and reverse logistics
Krishnan et al. [20]	To identify any operational and resource inefficiencies present in the food SC by environmental impact assessments and propose a framework for its redesign	Indian food SC

(continued)

Table 4.2 (continued)

References	Objectives	Context
Pinto and Diemer [30]	To determine the way in which applying different SC integration strategies based on raw material self-sufficiency and retaining the property of resources can affect CE	European steel industry
Yadav et al. [38]	To develop a framework to overcome sustainable SC challenges through I4.0 and CE-based solution measures	Indian automotive SC

4.3.2 Research Methodology and Methods

According to Dangayach and Desmukh [8], the research methodologies classification of the reviewed works is as follows: (1) conceptual, basic or fundamental concepts; (2) descriptive, an explanation or description of the process or content and performance measurement issues; (3) empirical, study data from existing databases, literature reviews, case studies and taxonomy or typology approaches; (4) exploratory cross-sectional by surveying at one time point; (5) exploratory longitudinal, where data collection was done at two time points or more. Table 4.3 summarises the research methodology followed in the reviewed works.

Here conceptual approaches are based mainly on systematic literature reviews. Descriptive methodologies generally propose frameworks validated through performance measure systems or indicators. Empirical approaches address case studies and practical examples. In this empirical methodology, the LCA methodology has been applied by several works. Finally, it is worth highlighting that analytical approaches and real-world applications scarcely appear in the reviewed papers.

4.3.3 Benefits

Table 4.4 presents the main benefits identified throughout the reviewed papers.

4.3.4 Limitations and Critical Points

Table 4.5 summarises the main limitations and critical points identified throughout this review.

Table 4.3 Research methodology (RM) and methods

References	RM	Methods
Winkler and Kaluza [36]	Conceptual	Generic structure, principles and economic and ecological measures
Zhu et al. [41, 42]	Exploratory cross-sectional	Questionnaires (396) and statistical techniques for data analysis
Zhu et al. [43]	Exploratory cross-sectional	Questionnaires (374) and statistical techniques for data analysis
Schrödl and Simkin [32]	Descriptive	Design science: problem recognition, suggestion, artefact development, demonstration and evaluation, conclusion
Ivanov et al. [19]	Empirical	Dynamic decomposition of a scheduling problem with the optimal program control theory and continuous variables and performance indicators
Barreto et al. [3]	Conceptual	Analysis and discussion
Butzer et al. [6]	Descriptive	Literature review and the balanced scorecard approach
Genovese et al. [13]	Empirical	The combination of a life cycle assessment (LCA) methodology and the environmentally extended multiregional input–output hybrid model
Ghani et al. [14]	Empirical	A two-step hierarchical approach: (i) economic input–output-based LCA (EIO-LCA) to quantify GHG emissions; (ii), a mixed integer linear programming (MILP) to identify optimal GHG emissions' reduction
Majeed and Rupasinghe [23]	Exploratory cross-sectional	A survey with 30 SAP consultants who are experienced in both technical and functional areas and 10 SAP users
Masi et al. [25]	Conceptual	Systematic literature review
Nasir et al. [29]	Empirical	LCA methodology utilising a combination of data provided by the industry and a reliable database

(continued)

Table 4.3 (continued)

References	RM	Methods
Tjahjono et al. [33]	Descriptive	A desk-based study utilising various types of literature, key performance identifiers and hypothetical example
Witkowski [37]	Conceptual	Presentation of concepts and examples
Zeng et al. [40]	Exploratory cross-sectional	Questionnaires (363) and structural equation modelling
Bag et al. [1]	Conceptual	Systematic literature review
Barata et al. [2]	Conceptual	Systematic literature review
Braun et al. [5]	Empirical	Deterministic calculations and simulations performed by the SC of the studied company
Dallasega et al. [7]	Empirical	Systematic literature review and case studies
Ding [11]	Conceptual	Systematic literature review
Geissdoerfer et al. [12]	Empirical	Four case studies
Govindan and Hasanagic [15]	Conceptual	Systematic literature review
Ivanov et al. [18]	Empirical	Literature review and analysis of practical examples
Lopes de Sousa Jabbour et al. [21]	Descriptive	Extension of state of the art by an agenda and roadmap proposal
Luthraa and Mangla [22]	Exploratory cross-sectional	Literature review, survey with 96 Indian manufacturers, research techniques based on analyses of explanatory factors and the analytical hierarchy process
Tseng et al. [34]	Conceptual	Literature review
Yang et al. [39]	Empirical	Case study
Bendaya et al. [4]	Conceptual	Systematic literature review
Daú et al. [9]	Empirical	Case study
Howard et al. [16]	Empirical	Literature review, company reports and case studies
Isernia et al. [17]	Empirical	Probability transition matrix methodology
Manavalan and Jayakrishna [24]	Empirical	Case study
Muñoz-Torres et al. [27]	Descriptive	Systematic literature review and framework proposal

(continued)

Table 4.3 (continued)

References	RM	Methods
Nascimento et al. [28]	Descriptive	Literature review, conceptual framework and focus group validation
Dev et al. [10]	Empirical	Taguchi experimental design
Van Engeland et al. [35]	Conceptual	Literature review
Krishnan et al. [20]	Empirical	Literature review and LCA methodology
Pinto and Diemer [30]	Empirical	LCA and system dynamics
Yadav et al. [38]	Descriptive	Literature review and seeking expert opinion

4.4 Discussion and Conclusions

The CE concept promotes continuous economic development without implying significant environmental and resources challenges. This is supported so that economic systems can, and must, operate according to the principles of the materials and energy cycles that sustain natural systems by emphasising the capacity of an organisation's waste being used as another organisation's resource via self-organisation capacity [41, 42]. Thus, one of the main challenges of implementing CE initiatives is to pay attention to economic implications [13]. So finding ways to align sustainable SC strategies with CE principles and understanding all the economic–environmental implications to do so are most important if we wish to broaden the limits of environmental sustainability, especially in intensive energy and materials industries [29]. In other domains for example, the main problems that prevent sustainability involve high costs and long times, little experience and training, the application of regulations, few commercial incentives, inefficient collaboration and coordination, lack of objective target reference points and barely any knowledge about end customers [11]. Govindan and Hasanagic [15] are in favour of promoting CE by a governmental perspective, i.e. laws, policies, risk reduction (through tax levies) and strict governance.

This CE paradigm will, in turn, be applied to an I4.0 context, specifically a logistics 4.0 context, which is understood as the combination of logistics with the innovations and applications of cyberphysical systems [3]. Industrial production systems must be balanced from the environmental, social, economic and technological points of view. Here it is important to highlight the work by Lopes de Sousa Jabbour et al. [21], who propose a first roadmap towards I4.0 and CE based on the ReSOLVE business model; or Dallasega et al. [7] distinguish different proximity dimensions: technological, organisational, geographical and cognitive. These findings demonstrate that not all I4.0 concepts affect all proximities to the same extent.

Table 4.4 Benefits

References	Benefits
Winkler and Kaluza [36]	A sustainable supply chain network (SSCN) approach makes possible to move from a flow economy to a closed circuit one what would benefit economic–ecological development by leading to improved competitive positions
Zhu et al. [41, 42]	Environmental-oriented supply chain cooperation is set up to reduce the use of material, water and energy throughout the SC by cooperating with suppliers and customers
Zhu et al. [43]	To opt for coercive equilibrium (command and control) with voluntary incentives and mechanisms as a favourable hybrid approach to apply effective ecological modernisation theory policies. International policies can influence environmental management practices to be set up by developing countries
Schrödl and Simkin [32]	The proposed model acts as a reference for up-to-date sustainable SC management issues and as a basis for the future development of an inter-organisational generic approach that depends on production
Ivanov et al. [19]	The results could be included in general iterative search procedures for optimal schedule programmes. It also extends the scope of the SC analysis by obtaining analytical solutions or robustness properties and investigating different adaptation policies in a scheduling problem
Barreto et al. [3]	The main challenges to apply the logistics 4.0 concept are identified
Butzer et al. [6]	Six perspectives are defined to assess reverse SCs: citizen and legislation, financial, interested parties, process, innovation and growth and flexibility
Genovese et al. [13]	The results suggest a positive influence from improving business sustainability by reinserting waste into the SC to manufacture products on demand
Ghani et al. [14]	This paper integrates EIO-LCA and MILP frameworks to identify the most pollutant industries in SCs of building structures
Majeed and Rupasinghe [23]	Proposal of a framework to integrate RFID with SAP ERP into an I4.0 context
Majeed and Rupasinghe [25]	To identify CE definitions and understandings, and to study its three SC configurations: eco-industrial parks, environmental and closed loop SCs
Nasir et al. [29]	The results show that transport elements dominate a larger proportion of the total emissions of a circular SC compared to a linear one
Tjahjono et al. [33]	To provide initial thought about SC 4.0

(continued)

Table 4.4 (continued)

References	Benefits
Witkowski [37]	To identify the benefits IoT, big data and I4.0 to cover customer demands and the development of SCs' logistics and management
Zeng et al. [40]	Theoretical and practical contributions for eco-industrial park firms to achieve sustainable SCs and to study CE capability
Bag et al. [1]	The identification of 13 key enablers of I4.0 that play a key role in driving SC sustainability: government support; support of research institutes and universities; law and policy on employment; among others
Barata et al. [2]	The identification of six avenues for future work: update existing studies to account for new technologies; to apply mobile technologies; produce samples of mobile SC cases; study the implications of regulatory compliance; develop maturity models for diagnostic and guidance; explore social aspects
Braun et al. [5]	It shows the routine for material efficiency improvements of SC elements. Moreover, investigating possible optimisation potentials in the SC of manufacturing enterprise is performed. The impact of CE activities is assessed
Dallasega et al. [7]	It identifies the proximity thresholds on its various dimensions that lead to loss of SC efficiency
Ding [11]	It proposes and analyses the Pharma I4.0 concept to adopt new technologies based on I4.0 to obtain a higher level of control and management throughout the product's life cycle using predictive analysis and proactive actions
Geissdoerfer et al. [12]	It identifies a change that requires changing conduct in consumers/suppliers where economic, environmental and social objectives must be promoted
Govindan and Hasanagic [15]	To implement CE into an SC, 13 drivers, 34 practices and 39 barriers are identified
Ivanov et al. [18]	The proposal of several conceptual frameworks regarding digital SC by providing the main technologies (big data analytics, I4.0, additive manufacturing, advanced tracking and tracing), applications and challenges
Lopes de Sousa Jabbour et al. [21]	The proposed roadmap combines novel concepts from the ReSOLVE business mode that act as a guide to implement CE principles and I4.0 technologies
Luthraa and Mangla [22]	18 challenges are identified and evaluated to contribute to I4.0 diffusion to lead towards smarter and sustainable manufacturing SCs
Tseng et al. [34]	The data-based analysis can be potentially used to optimise sustainable solutions that intend to reduce the intensities of resources and emissions of industrial systems

(continued)

Table 4.4 (continued)

References	Benefits
Yang et al. [39]	The dimensions of former research works about PSS are extended by incorporating the circularity of SCs
Bendaya et al. [4]	Avoidable waste production, security and efficiency throughout the food SC are identified as a potential convincing line to apply the IoT
Daú et al. [9]	The link among the triple bottom line, I4.0 and CSR allows the transition of linear to circular models and can improve the sustainable health SC 4.0
Howard et al. [16]	This paper reviews and analyses nine global companies and four practical cases that form a significant group of companies to investigate current and future practices in the development of CE indicators
Isernia et al. [17]	This article heads up the research community for defining customised policies to support the achievement of balanced e-waste collection performance
Manavalan and Jayakrishna [24]	This paper uses case-driven suggestions based on the 6Rs (recover, reuse, remanufacture, recycle, redesign, reduce) to leverage technology across SC so that organisations become more sustainable
Muñoz-Torres et al. [27]	The corporate sustainability assessment tool is implemented by a company into its SC management framework
Nascimento et al. [28]	The recommendation of a circular model to reuse scrap electronic devices by integrating web technologies, reverse logistics and additive manufacturing
Dev et al. [10]	The proposed model that integrates I4.0 and CE represents a real-time decision model for the sustainable reverse logistics system
Van Engeland et al. [35]	This paper provides a more updated vision of optimisation models in waste reverse SCs
Krishnan et al. [20]	Applying the conceptual framework to other industries can be done by this approach, wherein opportunities for improving operational efficiency and resource recovery for environmental sustainability can be similarly identified
Pinto and Diemer [30]	To provide new branches of strategic decision- and policy-making discussion in the European steel industry
Yadav et al. [38]	Proposal of a framework to overcome sustainable SC challenges

In short, this paper presents a preliminary literature review on research work oriented to SC 4.0 initiatives with CE principles. Here the objectives and application context and the research methodology of the reviewed works are analysed. An overview of the main benefits and limitations is addressed. This work identifies the

Table 4.5 Limitations and critical points

References	Limitations and critical points
Winkler and Kaluza [36]	Empirical projects to validate the SSCN proposal are lacking
Zhu et al. [41, 42]	The results cannot be generalised to other countries or specific industry sectors
Zhu et al. [43]	This study is limited to only one region of China
Schrödl and Simkin [32]	Green SC management, based on the SCOR model, lacks generality and covers only some parts of relevant aspects
Ivanov et al. [19]	Strong centralised control and lack of software tools to perform a comparative analysis with existing benchmark solutions. A higher level of heuristics is also required to improve computational efficiency
Barreto et al. [3]	It deals with the online transactions, the integration of new technologies and their better access for third parties and lack of computer security
Butzer et al. [6]	Lack of knowledge about evaluating international reverse SCs
Genovese et al. [13]	More relevant environmental indicators can be considered to make a comparison between linear and circular systems
Ghani et al. [14]	The application area of the proposed integrated approach is context specific
Majeed and Rupasinghe [23]	The results focus on a case study based on SAP ERP and the footwear and apparel industry
Masi et al. [25]	At the microlevel, it was impossible to differentiate among SC, product design, commercial strategy and the broader business model perspective
Nasir et al. [29]	Reliance on secondary data
Tjahjono et al. [33]	This is a preliminary work that requires further conceptual and empirical research
Witkowski [37]	Empirical research works that focus on logistics 4.0 strategies are needed
Zeng et al. [40]	Data should be collected from other countries to further validate the research hypotheses and conclusions of this study
Bag et al. [1]	The identified enablers need empirical testing in real-world SCs
Barata et al. [2]	Its limitations are the normal ones when performing a literature review as the analysis is delimited by the language, the keywords and the databases
Braun et al. [5]	CE scenarios for the example manufacturing enterprise and its SC are not examined in this analysis. Only the effect of flat 50% waste reintroduction into the economic circle for material supply is explored

(continued)

Table 4.5 (continued)

References	Limitations and critical points
Dallasega et al. [7]	It deals with the seasonality of projects and the large number of tasks and processes, which prevent productivity from improving
Ding [11]	It is based on only 33 scientific articles, of which only 1/3 are from high-impact journals. It mainly targets the downstream pharmaceutical SC
Geissdoerfer et al. [12]	A limited number of case studies and data collection are based only on a single interview per case
Govindan and Hasanagic [15]	The inclusion of multiple stakeholders and other theoretical frameworks, and considering the specific needs of a country or an industrial sector
Ivanov et al. [18]	Empirical results of the proposed conceptual frameworks are needed
Lopes de Sousa Jabbour et al. [21]	Organisations can face other difficulties when following the proposed roadmap due to distrust when integrating technological systems among SC partners and lack of technical knowledge about CE and I4.0
Luthraa and Mangla [22]	Some of the other challenges in different country contexts can be included in future studies. The Indian findings can be extended to other developing nations with marginal modifications
Tseng et al. [34]	The literature on “I4.0” and “CE” is scarce
Yang et al. [39]	Research in the field of circular SCs and business models is not yet mature, as indicated by it lacking agreed concepts and practices
Bendaya et al. [4]	Most studies have centred on conceptualising the IoT impact with analytical models and very few empirical studies. Moreover, most studies have focused on the delivery process and food SCs
Daú et al. [9]	More empirical studies must be done to analyse the replicability of the conceptual model proposed in other environments
Howard et al. [16]	The proposed framework is very concise and targets global companies
Isernia et al. [17]	The first limit lies in the analysed country-specific context, while the second one lies in the fact that it focuses on the collection part of the WEEE management system without considering other SC processes
Manavalan and Jayakrishna [24]	The paper focuses on a particular case study, and the suggestions to transform the linear SC into a circular one are specific and cannot be applied universally to any SC/organisation
Muñoz-Torres et al. [27]	The framework is not validated in a real-world case study

(continued)

Table 4.5 (continued)

References	Limitations and critical points
Nascimento et al. [28]	The perceptions of focus groups introduce subjectivity. In addition, the sample of experts is small and does not allow the results to be generalised
Dev et al. [10]	The results are context specific and deserve a more detailed analysis in terms of parameterisation and SC network structures for generalisation purposes. The study can be extended to multiple suppliers
Van Engeland et al. [35]	The framework is not validated in a real-world case study
Krishnan et al. [20]	In order to generalise the findings, further data collection is necessary. In addition, the specific focus on the cultivation, processing, packaging and transportation of a food SC is also a limiting factor
Pinto and Diemer [30]	Empirically addresses capital requirements for different investments in SC integration, the implications of investing in logistics and the specific environmental impacts that derive from these strategic changes
Yadav et al. [38]	The challenges and solution measures included in this study especially lie in the context of developing economies

need for more conceptual and empirical research to provide a framework and analytical models towards SC 4.0 with CE principles. Hence, optimisation and simulation models are required to support decision-making to optimise CE and I4.0 practices in SCs. Finally, the validation of these new optimisation and simulation circular SC 4.0 models should be validated with real-world applications.

Acknowledgements This work was supported by the Spanish Ministry of Science, Innovation and Universities project entitled "Optimisation of zero-defects production technologies enabling supply chains 4.0 (CADS4.0)" (RTI2018-101344-B-I00) and the Operational Program of the European Regional Development Fund (ERDF) of the Valencian Community 2014-2020 IDIFEDER/2018/025.

References

1. Bag S, Telukdarie A, Pretorius JHC, Gupta S (2018) Industry 4.0 and supply chain sustainability: framework and future research directions. Benchmark Int J 28(5): 1410–1450. https://doi.org/10.1108/BIJ-03-2018-0056
2. Barata J, Da Cunha PR, Stal J (2018) Mobile supply chain management in the Industry 4.0 era. J Enterp Inf Manage 31(1):173–192. https://doi.org/10.1108/JEIM-09-2016-0156
3. Barreto L, Amaral A, Pereira T (2017) Industry 4.0 implications in logistics: an overview. Procedia Manuf 13:1245–1252
4. Bendaya M, Hassini E, Bahroun Z (2019) Internet of things and supply chain management: a literature review. Int J Prod Res 57(15–16)

5. Braun AT, Kleine-Moellhoff P, Reichenberger V, Seiter S (2018) Case study analysing potentials to improve material efficiency in manufacturing supply chains, considering circular economy aspects. Sustainability 10(3):880
6. Butzer S, Schötz S, Petroschke M, Steinhilper R (2017) Development of a performance measurement system for international reverse supply chains. Procedia CIRP 61:251–256
7. Dallasega P, Rauch E, Linder C (2018) Industry 4.0 as an enabler of proximity for construction supply chains: a systematic literature review. Comput Ind 99:205–225
8. Dangayach GS, Deshmukh SG (2001) Manufacturing strategy literature review and some issues. Int J Oper Prod 21(7):884–932
9. Daú G, Scavarda A, Scavarda LF Julianelli V (2019) The healthcare sustainable supply chain 4.0: the circular economy transition conceptual framework with the corporate social responsibility mirror. Sustainability 11(12):3259
10. Dev NK, Shankar R, Qaiser FH (2020) Industry 4.0 and circular economy: operational excellence for sustainable reverse supply chain performance. Resour Conserv Recycl 153:104583
11. Ding B (2018) Pharma Industry 4.0: literature review and research opportunities in sustainable pharmaceutical supply chains. Process Saf Environ 119:115–130
12. Geissdoerfer M, Morioka SN, de Carvalho MM, Evans S (2018) Business models and supply chains for the circular economy. J Clean Prod 190:712–721
13. Genovese A, Acquaye AA, Figueroa A, Koh SCL (2017) Sustainable supply chain management and the transition towards a circular economy: evidence and some application. Omega 66:344–357
14. Ghani NMAMA, Egilmez G, Kucukvar M, Bhutta MKS (2017) From green buildings to green supply chains: an integrated input-output life cycle assessment and optimization framework for carbon footprint reduction policy making. Manage Environ Qual Int J 28(4):532–548
15. Govindan K, Hasanagic M (2018) A systematic review on drivers, barriers, and practices towards circular economy: a supply chain perspective. Int J Prod Res 56:278–311
16. Howard M, Hopkinson P, Miemczyk J (2019) The regenerative supply chain: a framework for developing circular economy indicators. Int J Prod Res 57(23):7300–7318
17. Isernia R, Passaro R, Quinto I, Thomas A (2019) The reverse supply chain of the e-waste management processes in a circular economy framework: evidence from Italy. Sustainability 11(8):2430
18. Ivanov D, Dolgui A, Sokolov B (2018) The impact of digital technology and Industry 4.0 on the ripple effect and supply chain risk analytics. Int J Prod Res 57(3):829–846
19. Ivanov D, Dolgui A, Werner W (2016) A dynamic model and an algorithm for short-term supply chain scheduling in the smart factory industry 4.0. Int J Prod Res 54(2):386–402
20. Krishnan R, Agarwal R, Bajada C, Arshinder K (2020) Redesigning a food supply chain for environmental sustainability. An analysis of resource use and recovery. J Clean Prod 242:118374
21. Lopes De Sousa-Jabbour AB, Chiappetta-Jabbour CJ, Godinho-Filho M, Roubaud D (2018) Industry 4.0 and the circular economy: a proposed research agenda and original roadmap for sustainable operations. Ann Oper Res 270:273–286
22. Luthraa S, Mangla SC (2018) Evaluating challenges to Industry 4.0 initiatives for supply chain sustainability in emerging economies. Process Saf Environ 117:168–179
23. Majeed AMA, Rupasinghe TD (2017) Internet of Things (IoT) embedded future supply chains for industry 4.0: An assessment from an ERP-based fashion apparel and footwear industry. Int J Supply Chain Manage 6(1):25–42
24. Manavalan E, Jayakrishna K (2019) An analysis on sustainable supply chain for circular economy. Procedia Manuf 33:477–484
25. Masi D, Day S, Godsell J (2017) Supply chain configurations in the circular economy: a systematic literature review. Sustainability 9(9):1602
26. McDonough W, Braungart M (2000) A world of abundance. Interfaces 30(3):55–65
27. Muñoz-Torres MJ, Fernández-Izquierdo MA, Rivera-Lirio JM, Ferrero-Ferrero I, Escrig-Olmedo E, Gisbert-Navarro JV, Marullo MC (2019) An assessment tool to integrate sustainability principles into the global supply chain. Sustainability 10(2):535

28. Nascimento D, Alencastro V, Quelhas O, Caiado R, Garza-Reyes J, Rocha-Lona L, Tortorella G (2019) Exploring Industry 4.0 technologies to enable circular economy practices in a manufacturing context: a business model proposal. J Manuf Technol Manage 30:607–627
29. Nasir MHA, Genovese A, Acquaye AA, Koh SCL, Yamoah F (2017) Comparing linear and circular SCs: a case study from construction industry. Int J Prod Econ 183:443–457
30. Pinto JT, Diemer A (2020) Supply chain integration strategies and circularity in the European steel industry. Resour Conserv Recy 153:104517
31. Sarkis J, Zhu Q, Lai KH (2011) An organizational theoretic review of green supply chain management literature. Int J Prod Econ 130(1):1–15
32. Schrödl H, Simkin P (2014) Bridging economy and ecology: a circular economy approach to sustainable supply chain management. In: Thirty fifth international conference on information systems, Auckland
33. Tjahjono B, Esplugues C, Ares G, Pelaez E (2017) What does industry 4.0 mean to supply chain? Procedia Manuf 13:1175–1182
34. Tseng ML, Tan RR, Chiu ASF, Chien CF, Ku TC (2018) Circular economy meets industry 4.0: can big data drive industrial symbiosis? Resour Conserv Recy 131:146–147
35. Van Engeland J, Beliën J, De Boeck L, De Jaeger S (2020) Literature review: strategic network optimization models in waste reverse supply chains. Omega 91:102012
36. Winkler H, Kaluza B (2006) Sustainable supply chain networks—A new approach for effective waste management. WIT Trans Ecol Environ 92:10
37. Witkowski K (2017) Internet of things, big data, industry 4.0. Innovative solutions in logistics and supply chains management. Procedia Eng 182:763–769
38. Yadav G, Luthra S, Jakhar SK, Mangla SK, Rai DP (2020) A framework to overcome sustainable supply chain challenges through solution measures of industry 4.0 and circular economy: an automotive case. J Clean Prod 254(1):120112
39. Yang M, Smart P, Kumar M, Jolly M, Evans S (2018) Product-service systems business models for circular supply chains. Prod Plann Control 29(6):498–508. https://doi.org/10.1080/09537287.2018.1449247
40. Zeng H, Chen X, Xiaoa X, Zhou Z (2017) Institutional pressures, sustainable supply chain management, and circular economy capability: empirical evidence from Chinese eco-industrial park firms. J Clean Prod 155(2):56–65
41. Zhu Q, Geng Y, Lai KH (2010) Circular economy practices among Chinese manufacturers varying in environmental-oriented supply chain cooperation and the performance implications. J Environ Manage 91(6):1324–1331
42. Zhu Q, Geng Y, Lai KH (2011) Environmental supply chain cooperation and its effect on the circular economy practice-performance relationship among Chinese manufacturers. J Ind Ecol 15:405–419
43. Zhu Q, Geng Y, Sarkis J (2011) Evaluating green supply chain management among Chinese manufacturers from the ecological modernization perspective. Transport Res E-Log 47(6):808–821