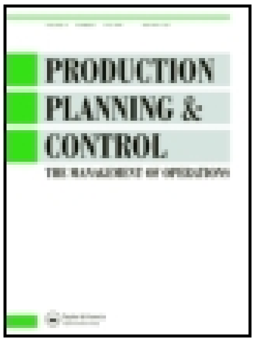

Taylor & Francis
Taylor & Francis Group

Production Planning & Control
The Management of Operations

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tppc20

Integrating circular economy and Industry 4.0 for sustainable supply chain management: a dynamic capability view

Haiyan Lu, Guoqing Zhao & Shaofeng Liu

To cite this article: Haiyan Lu, Guoqing Zhao & Shaofeng Liu (2022): Integrating circular economy and Industry 4.0 for sustainable supply chain management: a dynamic capability view, Production Planning & Control, DOI: 10.1080/09537287.2022.2063198

To link to this article: https://doi.org/10.1080/09537287.2022.2063198

PRODUCTION PLANNING & CONTROL
https://doi.org/10.1080/09537287.2022.2063198

Taylor & Francis
Taylor & Francis Group

OPEN ACCESS Check for updates

Integrating circular economy and Industry 4.0 for sustainable supply chain management: a dynamic capability view

Haiyan Lu[a], Guoqing Zhao[b] and Shaofeng Liu[b]

[a]Business School, Newcastle University, Newcastle, UK; [b]Plymouth Business School, University of Plymouth, Plymouth, UK

ABSTRACT

Circular economy (CE) and Industry 4.0 are recent business buzzwords that help organizations to maintain a circular flow and optimize the use of resources with technological supports to improve sustainability practice. Transition towards CE and Industry 4.0 is promising and yet challenging. As such, the aim of this research is to investigate how to integrate CE and Industry 4.0 in sustainable supply chain management (SSCM) in order to improve operational efficiency and sustainability performance. This study provides an analysis of the dynamic changes of drivers and barriers when integrating CE and Industry 4.0 and their related applications in operations and SCM through a systematic review of literature. From the results, a theoretical framework was derived for future research development.

ARTICLE HISTORY
Received 10 March 2019
Accepted 25 March 2022

KEYWORDS
Sustainable supply chain management; Industry 4.0; circular economy; dynamic capabilities

1. Introduction

Sustainable supply chain management (SSCM) is a prominent field that has received great attention globally in the last two decades. Driven by the external pressures from institutional regulation, market competition and stakeholders' requirements (Morali and Searcy 2013; Sarkis 2001; Lu et al. 2018), nowadays sustainability is not only implemented in company operations, but also integrated in key business processes in supply chain management (SCM) (Lambert et al. 2006; Ciliberti et al. 2009; Pagell and Wu 2009). Carter and Rogers (2008) suggested an organization should be economically viable, environmentally friendly and socially responsible and defined SSCM as the '*strategic, transparent integration and achievement of an organization's social, environmental, and economic goals in the systemic coordination of key inter-organizational business processes for improving the long-term economic performance of the individual company and its supply chains*' (Carter and Rogers 2008, p. 368). It is further argued environmental and social goals need to be achieved in the supply chain to meet customer requirements and relevant economic criteria (Seuring and Müller 2008).

SSCM has been integrated into SCM practices; for example, environmental purchasing, sustainable warehousing and packaging are widely implemented by different organizations (Carter and Jennings 2002; Zailani et al. 2012). Empirical results demonstrate that the adoption of SSCM practices can help organizations reduce waste, create a green image in the marketplace, increase job satisfaction, improve operational efficiency and achieve better financial performance (Baykasoğlu and Subulan 2016; Golicic and Smith 2013; Kähkönen, Lintukangas, and Hallikas 2018). However, despite the benefits of implementing SSCM, it involves complex systems and dynamic changes due to factors linked with both internal and external stakeholders (Beske 2012; Beske, Land, and Seuring 2014). As such, a dynamic capabilities (DC) view is adopted in this study to understand and integrate the evidence in a theory-led framework.

Recent research has extended SSCM to align with other emerging practices, including circular economy (CE) and supply chain innovation in Industry 4.0 (Gao et al. 2017; Geissdoerfer, Vladimirova, and Evans 2018; Telukdarie et al. 2018). Circular economy (CE) suggests a novel perspective to produce and consume in a systematic way for organisations (Su et al. 2013; Lopes de Sousa Jabbour et al. 2018) with a consideration of 3Rs – recycle, reuse and remanufacture (Lopes de Sousa Jabbour et al. 2018; Nobre and Tavares 2017; Peng et al. 2018; Tsai and Lai 2018). CE helps organizations with a supply chain loop in maintaining a circular flow to optimize the use of resources, such as energy and material to improve their triple bottom gains (Bressanelli et al. 2018; Henley 2013; Geissdoerfer, Vladimirova, and Evans 2018). Both of practitioners and academics have evolved in investigating the CE concept. For practitioners, the CE concept is underpinned in the 'take-make-dispose' economic model based on three principles, namely, design out waste and pollution, keep products and materials in use, and regenerate natural systems (Ellen MacArthur Foundation 2012). The prevailing linear model challenges the physical limits of Earth's natural resources and threatens the sustainable development of our economy. As such, CE emphasizes sustainable production and consumption as a viable model to enable the continual reuse

CONTACT Haiyan Lu ✉ Haiyan.Lu@Newcastle.ac.uk Business School, Newcastle University, Newcastle NE1 7RU, UK

of products and materials, and the use of renewable resources (Urbinati, Chiaroni, and Chiesa 2017; Esposito, Tse, and Soufani 2018). Transition to a CE not only provides environmental benefits such as reduction of production waste, but also generates social and economic benefits with net material savings and job creation potential (Schaltegger, Lüdeke-Freund, and Hansen 2012; Boons and Lüdeke-Freund 2013).

Industry 4.0, referring to the "Fourth Industrial Revolution", represents the use of contemporary technologies to improve operational efficiency (UNIDO 2017; Gates 2017). From a technological evolution perspective, the development of industrialization is moving towards Industry 4.0 with the application of modern information and communication technologies (Papadopoulos et al. 2022). Industry 4.0 is connected with the integration of Internet of Things - IoT (Lopes de Sousa Jabbour et al. 2018), cloud computing and big data analytics (Fatorachian and Kazemi 2018; Rehman et al. 2016), industry automation, data networks, and contemporary manufacturing technologies (Basl 2017; Luthra and Mangla 2018). In practice, the use of Industry 4.0-related technologies is expected to facilitate fundamental improvements in industrial processes from product design to manufacturing and delivery, and the establishment of smart factories (Kagermann, Wahlster, and Helbig 2013; Kang et al. 2016). For example, following the governmental plan, German manufacturing companies like Siemens and Bosch have already invested heavily in IoT and CPS-related initiatives (Liao et al. 2017). Other countries like the UK and South Korea have also presented long-term governmental plans for the manufacturing sector to ensure the benefit from what Industry 4.0 may deliver.

In the context of operations and SCM, the impact of Industry 4.0 on planning and control, production and logistics is crucial. Branke, Farid, and Shah (2016) indicated that the typical scenario of Industry 4.0 is the self-organizing factory, where goods find their way through the factory and exchange information with machines autonomously, based on customer requirements. Hence, Industry 4.0 enables the production system to make more intelligent decisions and enhances the collaborations across the supply chain (Branke, Farid, and Shah 2016). Hofmann and Rüsch (2017) noted that Industry 4.0 provides many opportunities to the development of logistics management by allowing real-time processing of consumption data, demand-oriented and dynamic milk-run collection and delivery of products. Lopes de Sousa Jabbour et al. (2018) and Stock and Seliger (2016) highlighted the sustainability implications of Industry 4.0, including the optimal use of resources, reduction of resource consumption and improvements in productivity. In practice, for example, manufacturing companies like Caterpillar and Renault, etc. have adopted Industry 4.0 to improve the efficiency of their supply chain and reduce wastage. However, challenges to Industry 4.0 for supply chain sustainability have also been identified. These challenges cover legal and ethical issues, organizational issues, strategic and technological issues (Luthra and Mangla 2018). According to Hofmann and Rüsch (2017), Industry 4.0 is still at its very beginning and it is worth exploring the enormous potentials that it may provide in the area of supply chain and logistics management.

Increasing numbers of literature has reviewed the relationship between CE and operations and SCM (Govindan and Hasanagic 2018; Ghisellini et al. 2016), CE and Industry 4.0 (Lopes de Sousa Jabbour et al. 2018), and the interlink between Industry 4.0 technologies and CE (Ellen MacArthur Foundation 2017; Lopes de Sousa Jabbour et al. 2018). This, on the one hand, shows the established research interest of the topic, while, on the other hand, revealing an essential research gap regarding to the investigation of the relationship among CE, Industry 4.0 and SSCM. In SSCM research, there is a lack of an overarching view integrating CE and Industry 4.0 and investigating their impacts on sustainability practice in operations and SCM. The underpinning mechanism concerning how CE and Industry 4.0 act together in influencing SSCM practices remains unclear. As such, this study is designed to review the current literature to fill the research gap; furthermore, to build a conceptual model to integrate CE and Industry 4.0 in SSCM, contributing to further sustainability research and practices. In this regard, this research aims to address the following research question:

> *RQ: To what extent can circular economy and Industry 4.0 be integrated to improve SSCM?*

This research is split into five sections. Section 1 presents the research background and discusses the research question. Section 2 portrays the designed research methodology. Section 3 presents the data analysis and results. In Section 4, the conceptual framework is built, drawing from the use of dynamic capability theory and the research findings in Section 3. To end, conclusions, along with contributions made to academic theory and industrial practice, are summarized in Section 5.

2. Research methodology

A systematic literature review (SLR) was selected as the research method for this study. Kitcharoen (2004) defined the SLR as a 'means of identifying, evaluating and interpreting all available research relevant to a particular research question, or topic area, or phenomenon of interest'. It is a well-acknowledged research method in operations and SCM study (Conde and Martens 2020) and SSCM research (Lu et al. 2018; Walker 2014) to generate the best evidence in a replicable process. This method employs a series of rigorous and transparent techniques to exhaustively and comprehensively search relevant studies in a way that allows minimization of bias and error, and overcoming of drawbacks associated with single studies (Saenz and Koufteros 2015; Friday et al. 2018; Melacini et al. 2018).

To ensure a scientific and rigorous approach, this study adopted a five-step research methodology proposed by Denyer and Tranfield (2009). Giving consideration to research validity and reliability, a research panel was formulated comprising four researchers with professional skills in conducting SLR in the field of operations, SCM and SSCM. Content analysis was employed in data analysis (Seuring and Gold 2012), and the results are presented and discussed in specific themes according to the research questions. A detailed description of each step is provided in the following sub-sections.

2.1. Step 1: Question formulation

The first step for conducting an in-depth SLR is to formulate research questions, which should develop a clear focus of the study (Denyer and Tranfield 2009). After conducting a conventional literature review and identifying the research gap for this study addressed in the introduction, the following sub-questions were formulated by the research panel to provide a clear focus:

- What are the key drivers and barriers for applying CE and Industry 4.0-related applications in the SSCM under the DC view?
- What are the main applications to integrate the CE and Industry 4.0 in the context of SSCM?

In general, it might be assumed that companies would mainly agree on sustainable development and apply it in their operations and SCM; likewise, CE is a field that companies and institutions would consider in their strategy making; business can hardly neglect Industry 4.0 in today's operations. However, all companies' activities and strategic implementation ought to be aligned with their capabilities, which are limited in dynamic changes, and that has been discussed in the introduction. As such, it is of importance to understand the key drivers and barriers for companies to benchmark their dynamic capabilities when they propose the integration of CE and Industry 4.0 in SSCM. The last sub-question is designed to understand the current research on integrating CE and Industry 4.0 in SSCM, specifically, the influence on environmental, economic and social sustainability. The findings will also reveal the mainstream research interest and the research gap for future study.

2.2. Step 2: Locating studies

This step involves searching relevant databases to build a comprehensive list of core contributions pertinent to the review questions while minimizing the amount of irrelevant literature (Duff 1996; Denyer and Tranfield 2009). In order to reduce bias, the research panel of experts conducted three initial sessions to discuss the searching strings and refine the inclusion exclusion before starting to search the database. Following that, the ISI Web of Science and Scopus were selected as the research sources because these two databases have some of the largest repositories of business research and are typically used in literature reviews (Hopp 2004; Carter and Easton 2011; Melacini et al. 2018). A detailed research protocol is given in Table 1. To identify publications, four categories of keywords were defined to search for studies:

- Words related to sustainability including sustainab*, green, environment*, ethic*, responsib*, triple-bottom-line, ecol*;
- Words related to CE including closed-loop, reduction, reuse, recycle;
- Words related to Industry 4.0including autonomous, automation, technology, and smart;
- Words related to operations and SCM including supply chain, purchasing, procurement, operations, logistics, production, and transport.

The search was based on all possible combinations of the four categories of keywords, using the "Topic" field to search. The search was conducted and updated to Apr 2021, and the timeframe covered all relevant published articles. Thus, the initial search yielded a total of 37,354 papers from ISI Web of Science and 530 papers from Scopus. Based on the initial searches, the research panel refined the selection to studies that are only academic articles and subjective relevance in management, business and transportation fields, and that yielded 856 papers for further evaluation.

2.3. Step 3: Study selection and evaluation

After the first two stages, the articles were entered into a detailed analysis to enable the research panel to distinguish the relevancy of each one (Tranfield, Denyer, and Smart 2003). The inclusion and exclusion criteria were chosen to select the most relevant papers for the research topic (see Table 2). In order to ensure a certain level of quality, only papers published in international peer-review journals could be selected for analysis (Touboulic and Walker 2015, Lu et al. 2018). Simultaneously, to ensure a rigorous and transparent SLR process, and to reduce any subjective bias and enhance validity, each paper was checked independently by all panellists in a blind procedure. Papers that were irrelevant to the CE and Industry 4.0 in the context of sustainable operations

Table 1. Search strings used for selecting papers.

Databases	Search strings
ISI Web of Science	(sustainab* OR (green OR environment* OR ethic* OR responsib* OR ’triple AND bottom AND line’ OR ’ecol’)) AND TOPIC: (’circular AND economy’ OR (’closed AND loop’ OR reduction OR reuse OR recycle)) AND TOPIC: (’industry AND 4.0’ OR (autonomous OR automation OR technology OR smart)) AND TOPIC: (’supply chain’ OR (supply OR purchasing OR procurement OR operations OR logistics OR production OR transport))
Scopus	(ALL (sustainab* OR (green OR environment* OR ethic* OR responsib* OR ’triple AND bottom AND line’ OR ’ecol’)) AND ALL (’circular AND economy’ OR (’closed AND loop’ OR reduction OR reuse OR recycle)) AND ALL (’industry AND 4.0’ OR (autonomous OR automation OR technology OR smart)) AND TITLE-ABS-KEY (’supply AND chain’ OR (supply OR purchasing OR procurement OR operations OR logistics OR production OR transport)))

Source: Authors.

and SCM were eliminated. Based on this procedure, 68 papers were selected.

To analyse the data, the panel firstly coded 15 papers independently, to cross check the validity of key terms and contents. Finally, all the selected papers were read in full and coded in NVivo 12. The selection process is shown in Figure 1.

2.4. Analysis and synthesis

After collecting the most relevant papers and finalizing the coding key terms and contents, the articles were entered into in-depth analysis and synthesis in NVivo 12. The purpose of analysis and synthesis is to examine and dissect individual studies and identify potential relations among the components, and then to classify the results of different studies 'into a new or different arrangement and developing knowledge that is not apparent from reading the individual studies in isolation' (Denyer and Tranfield 2009, 685). Content analysis was used to analyse the data (Seuring and Gold 2012; Lu et al. 2018), and finally the results were presented according to the research questions.

2.5. Reporting and using the results

After analysing and synthesizing all the papers, the emerging evidence is reported for results. Therefore, the general information of the studies and the main issues related to CE and Industry 4.0 in the context of sustainable operations and SCM will be described and discussed in the next section.

3. Descriptive analysis

In this section, an overview of the body of literature on circular economy and Industry 4.0 for sustainable supply chain management is provided, including year-wise distribution of

Table 2. Criteria for inclusion and exclusion of papers.

Inclusion & exclusion criteria	Rationale
Articles were published in peer-reviewed journals in English	Peer-reviewed journal papers are considered to have better quality than non-peer-reviewed journal papers
Only include papers that are in operations research, operations management, management and business study subject areas	The databases presented all articles, representing the inter-disciplinary nature of CE, Industry 4.0 and sustainability. To select the most relevant work, we only consider academic articles in the subject areas
Judge relevance by fully reading title, abstract, key terms, introduction and conclusion	By reading the title, abstract, introduction and conclusion, only papers focussing on the CE and Industry 4.0 in the context of SSCM were selected
Judge relevance by fully reading all remaining articles	Articles focussing on the CE and Industry 4.0 in the context of SSCM were selected

Source: Authors.

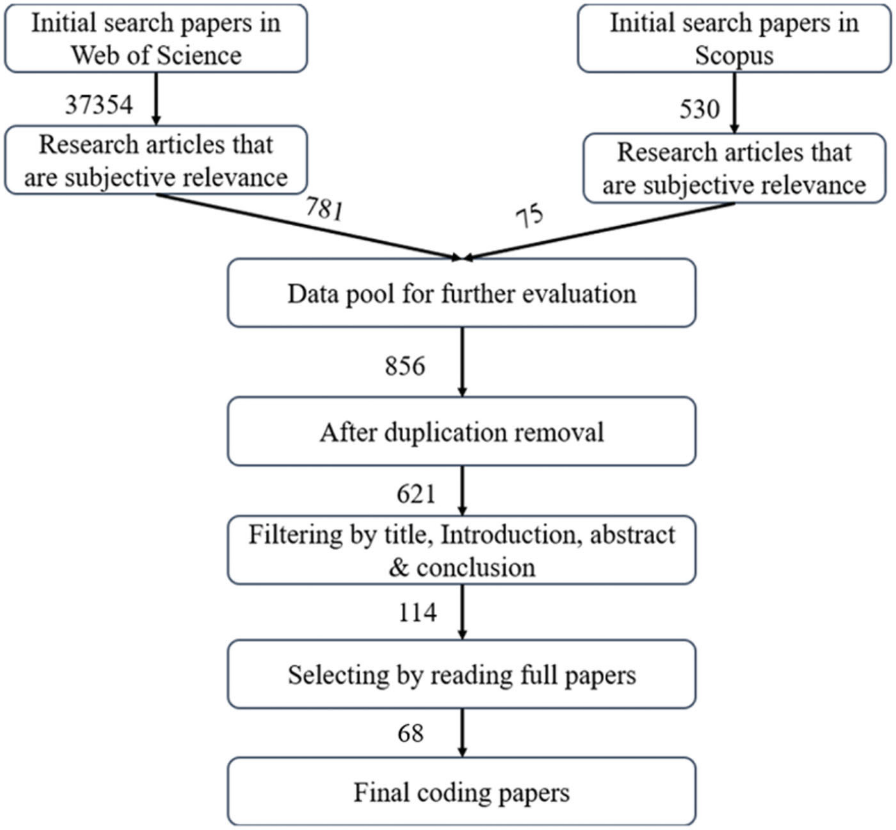

Figure 1. The selection process for the papers (Source: Authors).

the publications, journal-wise distribution of the publications, the author's country, and the research methodology adopted.

Regarding the year-wise distribution of the publications, we can see from Figure 2 that small variations have been observed until 2018, when there is a dramatic increase in the number of publications on circular economy and Industry 4.0 for sustainable supply chain management from 2018 onward. We assumed that the number of publications on the topic in the full year of 2021 would surpass that of 2019 and 2020 for several reasons. First, the COVID-19 pandemic situation across the globe would facilitate different Industry 4.0 technologies being applied in different industries, as people were forced to work at home to avoid being infected by COVID-19. Second, research related to sustainable supply chain management would continue to increase, as different countries proposed achieving a peak in carbon dioxide (CO_2) emissions before 2030 and achieving CO_2 emissions neutrality before 2060.

From Table 3 we can see that papers related to the topic are published in 47 different journals, showing a wise distribution in published journals. First, as noted in Table 3, Technological Forecasting & Social Change, Production Planning & Control, and the Journal of Cleaner Production are the journals that contain the highest number of papers related to the circular economy and Industry 4.0 for sustainable supply chain management. Technological Forecasting & Social Change aims to publish work that deals directly with the methodology and practice of technological forecasting and future studies as planning tools as they interrelate social, environmental and technological factors; Production Planning & Control aims to publish work related to operations and supply chain management; whereas the Journal of Cleaner Production targets work related to cleaner production. Second, the topic receives attention from different disciplines, including economic, engineering, environmental protection, and technology development (e.g. Trends in Food Science and Technology, Economics, Frontiers in Engineering Management). This indicates that the supply chain is complex, interconnected and involves a huge number of practitioners (e.g. suppliers, processors, wholesalers, distributors and retailers), which needs researchers to contribute not only from the supply chain perspective, but also from other perspectives. Thus, circular economy and Industry 4.0 can be applied to help to achieve a sustainable supply chain.

As for the author's country, most of the contributors are affiliated to China's institutions ($n = 15$, 22.06%), followed by Italy ($n = 6$, 8.8%), the United Kingdom ($n = 5$, 7.4%), South Africa ($n = 5$, 7.4%), and France ($n = 4$, 5.9%). It is interesting to note that researchers from South Africa have demonstrated great interest in the integrating of Industry 4.0 and circular economy for sustainable supply chain management for several reasons. First, South Africa has a unique advantage over other developed countries as it is not weighed down by infrastructure legacy issues and thus may have difficulty in embracing change (Deloitte 2017). Second, based on a survey conducted by PwC, approximately 27% of South African manufacturers rated their level of digitalization as high, and this value is expected to rise to 64% in the next five years (PwC 2021). With regard to authors from European countries, in addition to Italy, the United Kingdom, and France, researchers from Norway ($n = 2$, 2.9%), Germany ($n = 1$, 1.5%), Portugal ($n = 1$, 1.5%), Austria ($n = 1$, 1.5%) also published their work in scientific journals. The German authors seem less prolific, which is surprise, given that Germany is the originates of the concept of Industry 4.0. However, the statistics are related to the authors' affiliations, not to where Industry 4.0 and circular economy are implemented.

Regarding to the research methodology adopted, each paper was classified based on the primary methodology adopted, including theoretical and conceptual papers, case studies/interviews, surveys, modelling papers, and literature reviews (Seuring and Müller 2008; Winter and Knemeyer 2013). We found that modelling ($n = 30$, 44.1%) was the most popular research methodology, followed by theoretical and conceptual papers ($n = 14$, 20.6%), case studies/interviews ($n = 14$, 17.6%), literature reviews ($n = 10$, 14.7%), and surveys ($n = 2$, 2.9%).

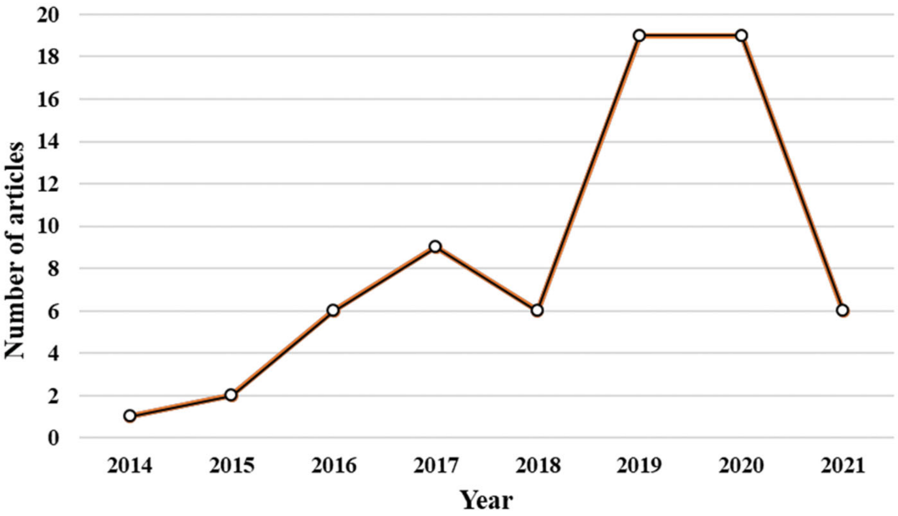

Figure 2. Year-wise distribution of publications (Source: Authors).

Table 3. Journal-wise distribution of the publications.

	Journal title	Article count
1	Technological Forecasting & Social Change	5
2	Production Planning & Control	5
3	Journal of Cleaner Production	5
4	International Journal of Production Economics	4
5	Sustainability	3
6	International Journal of Production Research	2
7	Omega	2
8	Journal of Manufacturing Technology Management	2
9	Entrepreneurship and Sustainability Issues	2
10	Industrial Marketing Management	1
11	Journal of Business Research	1
12	European Journal of Operational Research	1
13	Transportation Research Part D: Transport and Environment	1
14	Transportation Research Part E: Logistics and Transportation Review	1
15	Operations Research Perspectives	1
16	International Journal of Organisational Analysis	1
17	Science, Technology & Society	1
18	European Business Review	1
19	Management Decision	1
20	IEEE Transactions on Engineering Management	1
21	Enterprise Information Systems	1
22	Trends in Food Science & Technology	1
23	Computers and Electronics in Agriculture	1
24	Administrative Sciences	1
25	Journal of Food Engineering	1
26	Science of the Total Environment	1
27	Operations Management Research	1
28	International Journal of Information Management	1
29	Resources, Conservation & Recycling	1
30	Annals of Operations Research	1
31	CIRP Annals – Manufacturing Technology	1
32	Process Safety and Environmental Protection	1
33	Economics	1
34	Applied Sciences	1
35	Technology Analysis & Strategic Management	1
36	Operational Research – An International Journal	1
37	International Journal of Value Chain Management	1
38	Polish Journal of Management Studies	1
39	Computers in Industry	1
40	International Journal of Sustainable Transportation	1
41	Scientometrics	1
42	Frontiers of Engineering Management	1
43	Advanced Engineering Informatics	1
44	Additive Manufacturing	1
45	International Journal of Logistics Research and Applications	1
46	Journal of Environmental Management	1
47	Information Systems and e-Business Management	1
Total		68

Source: Authors.

4. Drivers of and barriers to integrating CE and Industry 4.0 from a dynamic capability view

This study adopts a dynamic capability view to understand the drivers of and barriers to integrating CE and Industry 4.0 in order to better guide practice improvement. Teece, Pisano, and Shuen (1997) generated a growing flow of research on dynamic capabilities to explain competitive advantage and performance on high velocity and dynamical changes of markets. The definition of dynamic capabilities is riddled with inconsistencies. According to Teece, Pisano, and Shuen (1997, 516), dynamic capabilities is the 'firm's ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments'. This approach was built considering several main elements which highlight the underpinning theories, including nature, role, context, creation, outcome and heterogeneity. The nature of the concept is an 'ability' or 'capacity', and the key role of dynamic capabilities as linked to the change of internal components, operating routines and resource routines of firms. More recently, Helfat (2007, 1) defined a dynamic capability as 'the capacity of an organization to purposefully create, extend or modify its resource base'. Dynamic capability is the ability to integrate and reconfigure internal and external competences for the specific purposes of integrating and reconfiguration resources and sustaining competitive advantage.

Often, dynamic capabilities are considered as firm-centred capabilities and nowadays they are discussed as a necessary factor to incorporate environmental and social responsibilities into the supply chain (Beske 2012; Beske, Land, and Seuring 2014; Qiao et al. 2020). Our study evaluates the drivers of and barriers to integrating CE and Industry 4.0, and further discusses the extent to which they increase or hinder dynamic capabilities in the SSCM context:

- Knowledge assessment: It is the category that enables the understanding of knowledge possessed by the supply chain partners and stakeholders (Defee and Fugate 2010).
- SC partner development: This category is a necessary capability for developing the partners in order to accomplish supply chain tasks and activities, following a sustainability strategy as a whole (Seuring and Müller 2008).
- Co-evolving: This category is related to the managers' reconnected webs of collaboration in order to generate new resources and synergies to enhance the overall supply chain performance (Pagell and Wu 2009).
- Reflexive SC control: This category emphasises constantly checking and evaluating business practices against requirements in SCM (Beske, Land, and Seuring 2014).
- SC re-conceptualisation: New partners could be local communities or third parties, not necessary part of the original supply chain (Pagell and Wu 2009), which can provide specific support and contacts.

4.1. Drivers

Observation from this study reveals that the main driver for integrating CE and Industry 4.0 in SSCM is the 'systemic change' (Moreno et al. 2019, 3) which creates better understanding of the digital intelligence system and identifies opportunities for integration and innovation. The systemic view requests the mature development and implementation of information system and technology in operations and SCM, systemic operation and stakeholder collaboration. Adopting dynamic capability theory allows us not only to understand the driving factors from operations and supply chain levels, but also from the supply network and the systemic perspectives (Table 4).

4.1.1. Knowledge assessment: analytic capability and information network system

According to Verdouw et al. (2018), the information system in Industry 4.0 supports the intelligent analytic capability and

Table 4. Drivers of integrating DC and Industry 4.0 in SSCM from a dynamic capability view.

DCs	Drivers	Description	CE and/or Industry 4.0	Key authors	No. of papers
Knowledge assessment	Analytic capability	Industry 4.0 technology enables companies to collect a large amount of data in real time, and automatically elaborates the data through analytics (Bressanelli et al. 2018)	Industry 4.0	Bressanelli et al. (2018), Yang et al. (2018), Mukherjee et al. (2021)	3
	Information in network system	It creates the knowledge base to understand the complexity of the information system and software platform for data-driven decision-making (Shamsuzzoha et al. 2016)	Industry 4.0	Shamsuzzoha et al. (2016), Yang et al. (2018), Jabbour et al. (2017)	11
SC Partner development	Stakeholder	The uptake of CE and Industry 4.0 faces various obstacles that require collaboration among multiple players – business, government, investors, society and communities (Yang et al. 2018)	CE and Industry 4.0	Jabbour et al. (2017), Despeisse et al. (2017), Kuznetsova, Zio, and Farel (2016), Pan et al. (2018)	13
Co-evolving	Integration & collaboration in SC	Advanced technologies and resources across the whole supply chain drive intensive integration and collaboration to achieve shared goals (Kouhizadeh, Zhu, and Sarkis 2020)	CE and Industry 4.0	Kouhizadeh, Zhu, and Sarkis (2020), Yang et al. (2018) Mukherjee et al. (2021)	12
	Network connectivity	Adoption of Industry 4.0 can lead to better connectivity and technological power for value creation (Fatorachian and Kazemi 2018)	Industry 4.0	Fatorachian and Kazemi (2018), Ramakrishna et al. (2020), Yang et al. (2018)	7
Reflexive SC control	SC activities	Industry 4.0 drives mass customisation, flexible and agile manufacturing, and keeps track of delivery (Parreno-Marchante et al. 2014)	Industry 4.0	Fatorachian and Kazemi (2018), Mladineo et al. (2018), Parreno-Marchante et al. (2014)	3
	Resource management	Smart devices and intelligent systems can optimise the operations system and resource consumption (Fatorachian and Kazemi 2018)	CE & Industry 4.0	Fatorachian and Kazemi (2018), Ramakrishna et al. (2020), Kristoffersen et al. (2020)	6
SC re-conceptualisation	Policy and legislative initiatives	Policymakers at all government levels play an important role in the CE and sustainable development (Lewandowski 2016)	CE & Industry 4.0	Lewandowski (2016), Pan et al. (2018)	9
	Systemic change	System design and system operations can drive practices related to green design of products and processes (Lopes de Sousa Jabbour et al. 2018)	CE & Industry 4.0	Lopes de Sousa Jabbour et al. (2018); Moreno et al. (2019)	2

Source: Authors.

data sharing in the network system. The current use of technologies, such as barcodes, radio frequency identification (RFID) and WSN in logistics and operations systems, essentially enhance real-time information collection for supply chain monitoring and improvement (Bibi et al. 2017; Parreno-Marchante et al. 2014; Fang et al. 2016). For example, the added value of RFID technology monitors different conditions for food quality control, including freshness, shelf-life and food waste identification (Bibi et al. 2017). RFID can also identify and stimulate the potential reused, recycled and remanufactured components to reduce wastage, addressing sustainability issues in supply chain operations (Iacovidou, Purnell, and Lim 2018). The efficient use of innovative technology dramatically increases the breadth and depth of data analysis to understand the behavioural changes in operations and sustainability practices (Yang et al. 2018).

4.1.2. *SC partner development: Stakeholder collaboration*

Being aligned with current sustainable supply chain literature (Carter and Easton 2011; Sarkis 2001; Lu et al. 2018), stakeholder expectation and collaboration is an ultimate driver for sustainable supply chain operations in the concepts of CE and Industry 4.0. Policy and new legislation describe new principles of sustainability practice, food traceability for example, and regulate new ways of information collection and exchange (Parreno-Marchante et al. 2014). Supportive governance and policies play an important role in creating an integrated approach, such as CE, to design, plan, support and coordinate for innovative and adaptive measures to environmental and social sustainability issues (Pan et al. 2018). Individual customer demands also drive companies and their supply chains to initially use Industry 4.0 to analyse customer specifications in the process of production. By using smart machinery and devices, organizations can transform customer requirements into production and operations efficiently (Fatorachian and Kazemi 2018).

4.1.3. *Co-evolving: Integration & collaboration and network connectivity*

Integrating the internet, smart manufacturing and Industry 4.0 as a broad scope of context enables companies to manage their distributed systems and value chain (Rehman et al. 2016). The information system generates a high level of connectivity in Industry 4.0, allowing managers to analyse potential limitations and optimize operational efficiency, driving integration and collaboration in sustainable supply chain operations (Fatorachian and Kazemi 2018; Jabbour et al. 2017). For example, the horizontal integration of global supply networks can potentially increase new business opportunities and resolve manufacturing obstacles (Yang et al. 2018).

4.1.4. *Reflexive SC control: SC activities and resource management*

Smart devices and intelligent data systems continuously drive manufacturing processes, optimization and production in resource and energy consumption to improve economic and environmental sustainability (Fatorachian and Kazemi 2018). Industry 4.0 encourages enterprises to adopt information-communication systems and smart devices into production and logistics systems, thus creating flexible and agile manufacturing, production networks and efficient delivery time (Mladineo et al. 2018). Industry 4.0 also allows companies to reflect on individual needs with mass customization production strategies (Fatorachian and Kazemi 2018). To an essential extent, such capability can generate significant efficiency and productivity in production and operations improvement.

Integrating CE and Industry 4.0 in SSCM is driven by optimal resource management (Bressanelli et al. 2018). Adopting smart devices and intelligent systems in Industry 4.0 can continuously optimize supply chain activities as mentioned; meanwhile, keeping track of and monitoring resources and material flow can optimize the use of natural resources and improve waste-to-resource manufacturing (Kristoffersen et al. 2020; Wang and Zhang 2020). Systemic operations are highly related to product design, manufacturing and processes for sustainable supply chain operations. The design of products that consume fewer raw materials and hazardous pollutants, extend life span and minimize waste in the early stage can increase the possibility of reused, recycled and remanufactured end-use components in the later disassembled stage (Lopes de Sousa Jabbour et al. 2018; Mukherjee et al. 2021).

4.1.5. SC re-conceptualization: Policy initiatives and s systemic change

Adopting sustainability practices in SCM requires not only integration from operations and supply chain levels, but also re-conceptualization with the whole social and eco system to incorporate dynamical changes in business scenarios. Cost and power are recognized as the major factors that drive CE process in SCM in demand patterns, product design and regeneration, and respective tax laws (Wang and Zhang 2020; Ramakrishna et al. 2020). New legislative initiatives in many regions, such as in the EU, US and China, have made regulations to respond to these dynamic changes and new concerns (Parreno-Marchante et al. 2014; Pan et al. 2018; Lewandowski 2016). For example, most EU countries have explicit waste management policies requiring electrical and electronic equipment to be mandatorily displayed in order to collect and recycle disposal from end consumer, reflecting the recycling objectives (Fang et al. 2016). The shift to CE requires a number of enablers and drivers to support the dynamic and systemic changes (Moreno et al. 2019).

4.2. Barriers

As discussed, companies can take benefits from enhanced dynamic capabilities when they imply CE and Industry 4.0 in practice; however, companies that are incompetent in mastering the new changes will face considerable challenges and barriers in sustainable supply chain operations. This research reveals that the main barriers in this regard can be decomposed as knowledge assessment, SC reflexive control, co-evolving and SC re-conceptualization (Table 5).

4.2.1. Knowledge assessment

Knowledge and skill incompetency is one of the biggest barriers in integrating CE and Industry 4.0. Industry 4.0 technologies require companies to capture and make sense of machine-generated data; in other words, it is a big challenge for many companies to analyse big data and use relevant analytical technologies and models to create value in their supply chain (Fatorachian and Kazemi 2018). In practice, it is important to have professional knowledge and necessary skills among the workforce for sustainability practices (Liboni, Liboni, and Cezarino 2018; Sjodin et al. 2018); as such, operations performance is significantly related to the development of employees' skills and talents (El-Kassar and Sigh 2018; Liboni, Liboni, and Cezarino 2018). To some extent, many limitations may be encountered in life cycle design such as awareness and implementation, information sharing for design specifications and the reuse, repair and history of the returned products (Yang et al. 2018), and for the retention of employees with innovative capabilities.

4.2.2. SC reflexive control

One problem addressed in adopting CE and Industry 4.0 is regarded as a trade-off of increasing traceability, transparency and sustainability practices, and the difficulty of controlling the complex and reflexive system. In the manufacturing and remanufacturing system, the quality of used products is a critical factor that influences the incentive paid to customers, remanufacturing cost, collection rate and lead time (Lopes de Sousa Jabbour et al. 2018).

In addition, cost is another considerable barrier. Using advanced technology and building the integration system is costly, for example the costs of data collected and recorded in the technologic system, such as RFID, and application in leveraging traceability in sustainable supply chain operation (Parreno-Marchante et al. 2014). With the maturity of technology development, the cost could be decreased in theory; however, proactive firms willing to sustain their market-leading positions need to pay the price at the current stage.

Operations uncertainty and security issues are other significant barriers that companies face when implementing CE and Industry 4.0. In a volatile business environment, when companies push forward their practice of remanufacturing, recycling, reusing and even regeneration, they ought to take into account the high uncertainty regarding operations competencies in inventory, logistics (Bag, Gupta, et al. 2021) and returns on investment (Lopes de Sousa Jabbour et al. 2018). In addition, smart factories and IoT contain inherent vulnerabilities regarding interference and cyber-attack, challenging the safeguards and security procedures for sustainable supply chain operations (Fatorachian and Kazemi 2018).

Table 5. Barriers to integrating DC and Industry 4.0 in SSCM from a dynamic capability view.

DCs	Barriers	Description	CE and/or Industry 4.0	Key authors	No. of papers
Knowledge Assessment	Challenges in data analysis	Analysing data in Industry 4.0 requires different structures, a process that can be a big challenge (Fatorachian and Kazemi 2018)	Industry 4.0	Fatorachian and Kazemi (2018)	1
	Knowledge and working capabilities	The workers in Industry 4.0 need to have innovative capabilities, skills and knowledge to manage the resources in Industry 4.0 and CE to achieve competitive advantages (El-Kassar and Sigh 2018)	CE & Industry 4.0	El-Kassar and Sigh (2018), Liboni, Liboni, and Cezarino (2018), Yang et al. (2018)	4
SC reflexive control	Used product quality level	The quality of used products affects the return rate, buy-back price and remanufacturing costs	CE	Lopes de Sousa Jabbour et al. (2018)	2
	Cost	High cost of investing in equipping Industry 4.0 technology, devices and personnel training is a highlighted drawback for many companies to make new changes (Parreno-Marchante et al. 2014)	Industry 4.0	Parreno-Marchante et al. (2014)	2
	Uncertainty and Security issue	Companies practising CE and Industry 4.0 face high levels of uncertainty regarding operations bottlenecks and information security (Bag, Gupta, et al. 2021)	CE and Industry 4.0	Bag, Dhamija, et al. (2021), Sjodin et al. (2018), Fatorachian and Kazemi (2018)	3
SC co-evolving	Structural and behavioural challenges	The CE and Industry 4.0 technologies pose a challenge for processing dynamic changes requiring a high level of integration across the supply network (Wang and Zhang 2020)	CE & Industry 4.0	Wang and Zhang (2020), Bag, Dhamija, et al. (2021)	7
SC re-conceptualisation	Standards and legislation	Lack of a commonly accepted definition and standards for remanufactured products (Yang et al. 2018)	CE	Yang et al. (2018)	1

Source: Authors.

4.2.3. *SC co-evolving and re-conceptualization: the complexity of dynamic systems*

The systemic perspective, on the one hand, drives an integrated view of sustainability practice; on the other hand, it imposes the challenge and difficulty of establishing the required dynamic system. Reliable information must be shared in a real-time manner throughout the whole supply chain to enable a quick response to changes. This would lead to great demands on flexibility and agility to facilitate the dynamic construction of temporary processes and network transparency of the supply chain (Verdouw et al. 2018). However, many supply chain actors, such as small and medium-sized enterprises (SMEs), might find it challenging to invest in advanced technologic and information systems for fulfilling the requirement of transparency and integration. Data overflow is another barrier in the complex dynamic system (Sjodin et al. 2018). For example, the design and operation in the engineering system requires specific methodologies to capture and solve the structural and behavioural challenges (Kuznetsova, Zio, and Farel 2016). However, uncertainty and risks will increase as inefficient use of innovative technology and information system may increase the system's complexity (Sjodin et al. 2018). Instead of losing focus, companies might need to strategically decide on their core competencies along with consideration of the complex and dynamic nature, rather than be driven by the overwhelming data system.

Due to the complexity of the dynamic system, it lacks standards and legislation for a common acceptance of CE and remanufactured products (Yang et al. 2018). It creates the most prevalent barrier to earning consumer trust in remanufactured products and restricts international trading in certain countries.

5. Integrating CE and Industry 4.0 in SSCM

With respect to the negative effects and potential challenges for human development in the past and present, this study has captured the economic, environmental and social value of sustainability in supply chain operations when considering the influence from CE and Industry 4.0 (Table 6).

5.1. *Economic sustainability*

5.1.1. *Operational efficiency*

By adopting CE and Industry 4.0, companies and their supply chains potentially increase operations efficiency in terms of increasing material flow, and enhancing the tracking and tracing system. CE requires the adaptation of supply chain sustainability across all operational process, including produce design, process, production and logistics (Lopes de Sousa Jabbour et al. 2018). Meanwhile, Industry 4.0 supports decision-making systems, helping to increase material flow and reduce life cycle impacts to build companies' capabilities, as a result of improving operational, financial and sustainable supply chain performance (Peng et al. 2018). The emergence of innovative technologies creates opportunities for changing how firms interact conventionally with a better

Table 6. Integrating CE and Industry 4.0 in SSCM.

Dimensions	Core concept	Key authors	No. of papers
Economic sustainability			**32**
Operational efficiency	Companies and their supply chains potentially increase operational efficiency in terms of increasing material flow, and enhancing the tracking and tracing system	Lopes de Sousa Jabbour et al. (2018), Despeisse et al. (2017), Verdouw et al. (2018)	21
Operational costs	Higher operational efficiency in terms of tracking and tracing system can reduce overall costs (Iacovidou, Purnell, and Lim 2018)	Iacovidou, Purnell, and Lim (2018), Nobre and Tavares (2017), Bag, Dhamija, et al. (2021), Dev, Shankar, and Swami (2020)	7
Risk control	Integrating CE and Industry 4.0 can mitigate the system risks and error (Mukherjee et al. 2021)	Nobre and Tavares (2017), Liboni, Liboni, and Cezarino (2018), Mukherjee et al. (2021)	4
Environmental sustainability			**52**
Environmental impact	CE and Industry 4.0 can increase the sustainability of products, processes and services while decreasing the environmental impacts (Lopes de Sousa Jabbour et al. 2018)	Kuznetsova, Zio, and Farel (2016), Liboni, Liboni, and Cezarino (2018), Lopes de Sousa Jabbour et al. (2018)	21
Waste reduction	Companies enhance their capabilities in emphasising waste reduction, which is strongly related to reuse, recycle and remanufacture to reduce waste in SCM (Liboni, Liboni, and Cezarino 2018)	Liboni, Liboni, and Cezarino (2018), Rogetzer, Silbermayr, and Jammernegg (2019)	19
Resource consumption reduction:	Integrating CE and Industry 4.0 is one of the alternatives to resolve resource scarcity to reduce resource consumption for sustainable development	Kuznetsova, Zio, and Farel (2016), Kuo and Smith (2018), Rehman et al. (2016), Wang and Zhang (2020)	12
Social sustainability			**11**
Safety	Integrating CE and Industry 4.0 can improve safety levels for workforce and society	Liboni, Liboni, and Cezarino (2018), Sjodin et al. (2018)	4
Job satisfaction	Reducing repetitive and fatiguing work activities in Industry 4.0 assists in improving job satisfaction	Sjodin et al. (2018)	2
Job opportunity	Job opportunities can be created in the after-sales service market; however, automation could cause concerns regarding job security and redundancy	Fatorachian and Kazemi (2018), Yang et al. (2018), Ramakrishna et al. (2020)	5

Source: Authors.

communication system and information flow (Despeisse et al. 2017; Bag, Gupta, et al. 2021). Firms are able to make radical improvements to material efficiency by eliminating material waste in all processes with a transparent flow (Despeisse et al. 2017).

Industry 4.0-based supply chains meet the need to build a comprehensive tracking and tracing system for improving operational efficiency in the contemporary supply chain (Verdouw et al. 2018; Bag, Gupta, et al. 2021). It is of significance while challenging for international logistics and supply chains to address the sophisticated nature in each individual industry, such as perishability in the food supply chain for quality control. Traceability and the tracking system in Industry 4.0 enable companies and the end consumers to obtain all the information about the forward supply chain and potentially to trace the backward supply chain to locate and assess the lifetime of the goods and identify CE for sustainability practices (Franco 2017; Bibi et al. 2017).

5.1.2. Operational costs

The creation of operational efficiency in such tracking and tracing systems can reduce operational costs (Iacovidou, Purnell, and Lim 2018; Nobre and Tavares 2017). With the application of Industry 4.0 and CE, the production of core produce and competencies can be improved for economic growth (Lewandowski 2016; Zhang et al. 2017) with lower production costs (Nobre and Tavares 2017), such as transportation costs (Mladineo et al. 2018), project costs (Iacovidou, Purnell, and Lim 2018), and data utilization costs (Rehman et al. 2016). For example, by tracking and tracing perishable products, firms can improve the management of food waste and recalls under better control of products and processes; meanwhile, the automated scanning can reduce labour and enhance stock control to reduce operational costs (Parreno-Marchante et al. 2014).

5.1.3. Risk control

Finally, risk control is a vital factor to be considered for economic sustainability. CE drives positive and continuous development where it optimizes the use of natural capital and social resource while minimizing the system risks (Nobre and Tavares 2017). Meanwhile, the use of advanced technology and information system can substantially reduce the system errors; for example, it can reduce transportation processes, unnecessary material flows and delivery mistakes, and increase data transparency throughout the whole supply chain via smarter logistics (Liboni, Liboni, and Cezarino 2018). In this regard, supply chain systematic risks could be monitored and controlled in the integration of technological, operational and systematic competencies (Mukherjee et al. 2021).

5.2. Environmental sustainability

5.2.1. Decrease environmental impact

When enterprises move towards sustainability, CE and Industry 4.0 increase the process of developing new products, processes and services while decreasing environmental impacts, which can be summarized as the factors of eco-innovation and pollution and greenhouse gas emission reduction (Cai and Choi 2021; Lopes de Sousa Jabbour et al. 2018).

The overarching concept of eco-innovation is to interlink industrial systems and energy and material consumption from the eco-system (Kuznetsova, Zio, and Farel 2016). It is the process of 'developing new products, processes or services which provide customer and business value but significantly decrease environmental impacts' (Fussler and James 1996, In: Kuo and Smith 2018, 208). The 3Rs and supply chain loop systematically recover, restructure and upgrade supply chain functions from industrial waste to support sustainable implementation (Tolio et al. 2017). There are five dimensions of eco-innovation devised by the European Commission: eco-innovation inputs, eco-innovation activities, eco-innovation outputs, resource efficiency and socio-economic outcomes (Kuo and Smith 2018). The implementation of these dimensions is significantly related to corporate competitiveness and environmental performance when firms and their supply chains enhance green product innovation (El-Kassar and Sigh 2018).

The forms of pollution and greenhouse gas emission reduction can be decomposed as gas, liquid, solid and sound (Peng et al. 2018); for example, reducing water pollution in tourism (Pan et al. 2018) and hazardous chemical pollution (Franco 2017). Greenhouse gas emissions, such as CO_2 emissions, seriously worsen the global climate (Tsai and Lai 2018; Yang et al. 2018). Through proper reuse, repairing and maintenance of used products in CE, it is efficient to reduce carbon emissions and toxicity and optimize the use of virgin resources (Iacovidou, Purnell, and Lim 2018). In addition, the enhanced process in Industry 4.0 enables the reduction of pollution and greenhouse gas emissions in a tracking system with sufficient data support (Liboni, Liboni, and Cezarino 2018). Supported by Industry 4.0, the reduction of environmental impacts can be improved by product design, material selection and efficient recycling processes (Jose and Ramakrishna 2018; Kristoffersen et al. 2020).

5.2.2. Waste reduction

In integrating CE and Industry 4.0, companies enhance their capabilities in terms of waste reduction, which is strongly related to the reuse, recycling and remanufacturing of end-of-life product to reduce waste in SCM (Nascimento et al. 2019). Manufacturers take responsibility for the end-of-life products and turn wastes into reusable energy as circular resources (Kuo and Smith 2018; Lewandowski 2016; Pan et al. 2018); for example, using robots and machine learning to revolutionize waste sorting and product disassembly systems (Liboni, Liboni, and Cezarino 2018) to reduce waste. Through the 3Rs, the highest value of the physical properties of a product can be kept and avoid emissions generation (Moreno et al. 2019; Fang et al. 2016). Taking advantage of Industry 4.0, it is aimed to radically improve the CE practice for resource efficiency and eliminate waste (Despeisse et al. 2017; Rogetzer, Silbermayr, and Jammernegg 2019).

5.2.3. Resource consumption reduction

It seems that integrating CE and Industry 4.0 is one of the alternatives to resolve resource scarcity in order to reduce resource consumption for sustainable development (Wang and Zhang 2020). The primary focus of the 3Rs, or the extended 6Rs, is to reduce environmental impacts by reducing energy and raw material consumption for operations and resources efficiency (Kuznetsova, Zio, and Farel 2016; Kuo and Smith 2018). Resource consumption and waste emissions are minimized by 'slowing, closing, and narrowing material and energy loops' (Franco 2017, 834). Meanwhile, Industry 4.0 such as data sharing and big data analytics enables knowledge to drive value creation (Rehman et al. 2016). The supporting technologies and information play a fundamental role in sustainability operations and SCM.

5.3. Social sustainability

Observation in this study reveals that social sustainability in operations and SCM is yet at the infant stage in the integration of CE and Industry 4.0. ***Safety*** is a positive side of integrating CE, particularly Industry 4.0, into sustainability practice. Automation in processes may reduce potential errors such as industrial accidents and improve human safety (Liboni, Liboni, and Cezarino 2018; Sjodin et al. 2018). At the societal level, it increases confidence about safety for the end user and improves welfare because of the benefits generated from the reuse of construction materials (Iacovidou, Purnell, and Lim 2018). Increasing job satisfaction is another factor of social sustainability in this integration due to the fact that repetitive and fatiguing work activities are reduced in Industry 4.0 (Sjodin et al. 2018). Job opportunity seems to be the debateable topic in sustainability. On the one hand, it is argued that new business and job opportunities can be created in the after-sales service market (Yang et al. 2018). However, on the other hand, the technological changes, especially the transformation of automation, could cause concerns regarding job security and redundancy (Fatorachian and Kazemi 2018; Parreno-Marchante et al. 2014; Ramakrishna et al. 2020). Yet, it is in a revolution for implementing advanced technologies in industrial, where not only economic and environmental sustainability, but also social and human responsibilities should be taken into consideration in the long term.

6. Discussion

6.1. Integration of CE and Industry 4.0 for SSCM

The principle of sustainability and SSCM is heavily dependent on the availability of resources (Baykasoğlu and Subulan 2016; Golicic and Smith 2013). However, it is now challenged by an unprecedented rise in demand for the finite supply of resources (Yang et al. 2018). Therefore, this study aims to investigate how CE and Industry 4.0 integrate to improve sustainable SCM.

Based on the current literature (e.g. Lewandowski 2016; Govindan and Hasanagic 2018), this study found that there is a great connectivity between Industry 4.0 and CE; in

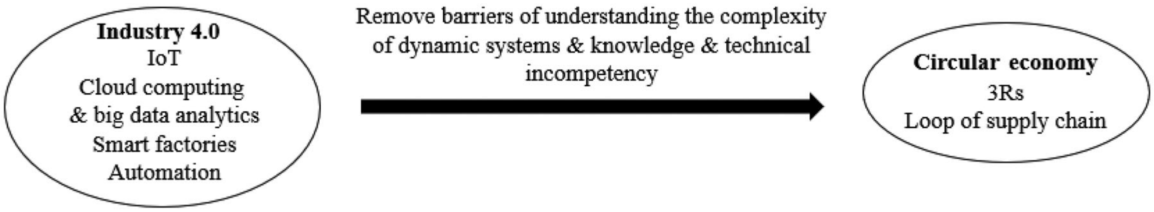

Figure 3. Connection of Industry 4.0 and CE (Source: Authors).

particular, the implication of innovative technologies and information system in Industry 4.0 enables CE application in SSCM (Figure 3). The main driver of CE is to maximize the utility and value of products and resources (Lewandowski 2016; Tolio et al. 2017). On the other side, there are considerable barriers when adopting CE in SSCM. The complexity of the dynamic system indicates s the difficulty of using advanced technologies and data analytical skills (Verdouw et al. 2018; Sjodin et al. 2018) in a high level of integration across the supply network (Wang and Zhang 2020). As such, the use of advanced technologies in smart factories and automation supports the processes of reusing, recycling and remanufacturing to extend the material lifespan in the closed and opened loops of the supply chain (Tseng et al. 2018; Pan et al. 2018; Mukherjee et al. 2021), and that improves resource management in reflexive control (Fatorachian and Kazemi 2018). Meanwhile, the use of IoT and big data analytics plays a significant role in enhancing a company's knowledge competency for further analysis and to understand the intellectualization of the existing system, helping to support decision-making and the better implementation of CE (Zhang et al. 2017; Mukherjee et al. 2021). Drawing on this finding, we propose that:

> *Proposition 1: The implications of Industry 4.0 and CE are connected; in particular, Industry 4.0 tackles the barriers to understanding the complex mechanism in the dynamic system and enhancing knowledge assessment and reflexive control for adopting CE.*

6.2. The roadmap towards SSCM: a dynamic capability view

In SSCM research, the respective dynamic capabilities for SSCM can be observed to have a supporting influencing on the three pillars of sustainability (Beske 2012). Based on the definition from Helfat (2007) and the research findings in this study, we propose a framework for mapping SSCM with integration of Industry 4.0 and CE from a dynamic capability view (Figure 4).

Being aligned with a study from Beske (2012), the framework in this study includes five categories of dynamic capabilities, taking into account knowledge assessment, partner development, co-evolving, reflexive supply chain control, and supply chain re-conceptualization, to analyse the drivers of and barriers to integrating CE and Industry 4.0 in SSCM practices. It was discussed above how Industry 4.0 can improve knowledge sharing and understanding for CE implementation. We argue that this is in a dynamic process in which, the more knowledge and skills companies incorporate, the more competencies they can implement Industry 4.0 and CE for SSCM, and that the argument issupported by the study from Zhang et al. (2017). By improving their analytic capability and information network system, potentially, companies can better manage the product lifecycle and reverse logistics to reduce their environmental impact (Franco 2017; Liboni, Liboni, and Cezarino 2018). However, this is not a linear progress; rather, it evolves when companies keep improving their assessment of knowledge while tackling shortcomings and weakness in advanced technologies, smart devices and complex data analytical systems (Yang et al. 2018; Mukherjee et al. 2021). In addition, integrating CE and Industry 4.0 into operations practice substantially improves supply chain reflexive control, such as cost structure and material availability in the designed framework to better incorporate sustainability issues, such as labour arbitrage and wastage control and improve supply chain performance (Fatorachian and Kazemi 2018; Wang and Zhang 2020).

Integrating Industry 4.0 and CE-enhanced partner development improves partner development in a co-evolving process (Jabbour et al. 2017; Pan et al. 2018; Mukherjee et al. 2021). It is in a pervasive connectivity among supply chain partners, which enables constant feedback from physical devices and Industry 4.0 to improve production processes and delivery in SCM (Fatorachian and Kazemi 2018) for better management of environmental and human resources in SSCM (Kuo and Smith 2018; Yang et al. 2018). Likewise, optimal partner development is essential for CE, such as remanufacturing in the closed-loop supply chain (Mladineo et al. 2018). However, with integration and collaboration in the supply network, it is important, yet difficult, to invest in and share the same vision for Industry 4.0 and CE (Kouhizadeh, Zhu, and Sarkis 2020; Yang et al. 2018; Mukherjee et al. 2021).

The integration of CE and Industry 4.0 enforces supply chain re-conceptualization to address the dynamic changes for SSCM in societies. Addressed in the current literature, different stakeholders, such as government policymakers, practitioners, educators and non-profit organizations, could enhance their knowledge sharing and integrate sustainability into policies and management practices (Pan et al. 2018). CE is increasingly important worldwide; for example, the G7 Summit Declaration of June 2015 launched the 'Alliance on Resource Efficiency' to promote CE. In turn, supply chain re-conceptualization fosters knowledge sharing and resource integration for Industry 4.0 and CE. When discussing the supply chain loop, it involves corporate decision-makers among multiple supply networks across different industries (Tseng

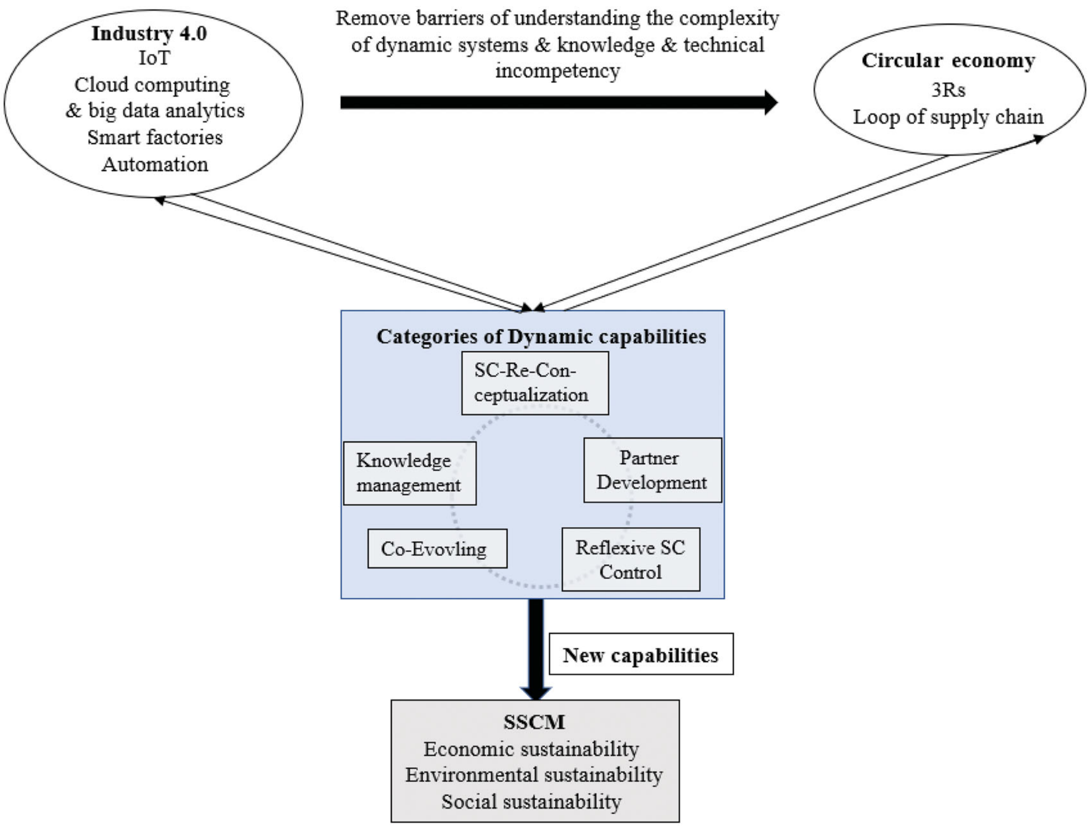

Figure 4. The roadmap to SSCM (Source: Authors).

et al. 2018). Drawing on the discussion above, we propose that:

> *Proposition 2: Industry 4.0 and CE enhance dynamic capabilities to incorporate SSCM; in turn, dynamic capabilities foster better knowledge assessment, supply chain partner development, co-evolution and re-conceptualization for CE and Industry 4.0 applications in operations and SCM.*

7. Conclusions

A recent report of the United Nations Industrial Development Organization (2017) indicates that Industry 4.0 is one of the accelerators of 'sustainable energy'. Integration of Industry 4.0 and CE can assist organizations to optimize their resources to enhance sustainability in supply chains. This study has found a substantial linkage between Industry 4.0 and CE, and further revealed the barriers to understand the complexity of dynamic systems and building knowledge and technical competency for implementing SSCM. This research proposes a conceptual framework that demonstrates how Industry 4.0 and CE can enhance dynamic capabilities for SSCM implementation, including economic, environmental and social sustainability in operations and SCM.

7.1. Theoretical and managerial contributions

Given the relative novelty, in academic research, of these two concepts, we hope to contribute to the literature by providing the necessary foundation to understand their scholarly and practical implications. To this end, we also posit some research propositions related to the diffusion of CE-Industry 4.0 practices.

This is one of the very first studies to understand Industry 4.0 drivers and CE context for managing sustainability implementation in operations and SCM. This study makes several theoretical and management-level contributions, given as follows:

- This study systematically reviews the drivers of and barriers to integrating CE and Industry 4.0 in SSCM from a dynamic capability view. The discussions have uncovered a holistic view of systemic changes together with operational and relational factors for further research on their implementation. The listing of drivers and barriers provides a checklist for practicing managers in managing the operational excellence of sustainable supply chains driven by Industry 4.0 and CE.
- By taking a dynamic capability view, this research provides a roadmap to managers in SSCM adoption. This would further enhance a theoretical understanding on micro and macro levels of operational issues in SSCM adoption and further improve SSCM practices by building dynamic capabilities integrated from CE and Industry 4.0. This study also generates theoretical propositions for supporting future research development.
- From a managerial perspective, considering the implication of the developed framework, CE has been embedded in the

Courtauld Commitment 2025 to reduce carbon emissions and improve process efficiency for organizational sustainability (Waste and Resources Action Programme 2018). Industry 4.0 has also been differentiated as a strategic agenda among manufacturers to reduce process waste. The developed conceptual framework in this study would further provide management with a better understanding of how to achieve sustainability in supply chain operations through CE and Industry 4.0. The drivers and barriers discussed in this study can also provide insights for managerial decision-making on where and how to invest in CE and Industry 4.0, according to the companies' capabilities and strategies.

7.2. Future research

This paper has its own limitations. The research findings are based on the current literature; therefore, it could be contested in terms of generalizing the implementation of results. For future research development, given that integrating CE and Industry 4.0 is a co-evolving and reconceptualized process, further studies can investigate this in depth, to explore the emerging contexts and the underlying mechanism. Specifically, the dynamic changes in different regions, industries and systems can show various characteristics and conditions; for example, during the COVID-19 pandemic, countries urgently introduced new regulations and integrated resources and capabilities across regions to ensure public health. The global supply chain is fairly fragile and optimizing dynamic capabilities by taking the best advantages from Industry 4.0, and reusing and redesigning resources in the global supplying network, is now more important than ever for sustainable development. Further research can examine to what extent the provided framework can or cannot work for different regions, such as how to enhance dynamic capabilities for industries in India to cope with COVID-19 disruptions in SSCM practice.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Notes on contributors

Dr. Haiyan Lu is an Assistant Professor in Operations and Supply Chain management at Newcastle University, UK. She is an active researcher on sustainable supply chain management, with a particular focus on the transform of environmental and social responsibilities in emerging economics. Her research is evidence-based and closely linked with industrial practices and government policymaking. Haiyan also works as government consultant in the Government of India. Her research has published in prestigious journals, such as Supply Chain Management: An International Journal, International Journal of Production Research, Production Planning and Control, and Computers in Industry.

Dr. Guoqing Zhao is a research fellow of EPIC project (eHealth Productivity and Innovation in Cornwall and the Isles of Scilly) at the University of Plymouth, UK. He participated projects from Horizon 2020 Programme and European Regional Development Fund. His research interests include knowledge management, supply chain resilience, supply chain risk management and eHealth technology. He has published in prestigious journals, including International Journal of Production Research, Computers in Industry, Production Planning & Control and among others. He got top cited award from International Journal of Production Research, and received well-acknowledged awards from subject conference and association, and Chinese government.

Shaofeng Liu is Professor of Operations Management and Decision Making at University of Plymouth, UK. Her expertise is in knowledge management, decision analysis, and emerging digital technology applications for supply chain management, resource efficiency, process improvement, quality management and value chain innovation. She has undertaken many influential funded projects from UK research councils and European Commission. Currently, she is the Principal/Co-Investigator for two UK funded projects and two projects funded by European Commission. She has published over 180 peer-reviewed research papers and 2 books. She sits on the Management Board for Euro Working Group on Decision Support Systems.

References

Bag, S., S. Gupta, and S. Kumar. 2021. "Industry 4.0 Adoption and 10R Advance Manufacturing Capabilities for Sustainable Development." *International Journal of Production Economics* 231: 107844. doi:10.1016/j.ijpe.2020.107844.

Bag, Surajit, Pavitra Dhamija, Shivam Gupta, and Uthayasankar Sivarajah. 2021. "Examining the Role of Procurement 4.0 towards Remanufacturing Operations and Circular Economy." *Production Planning & Control* 32 (16): 1368–1383. doi:10.1080/09537287.2020.1817602.

Basl, J. 2017. "Pilot Study of Readiness of Czech Companies to Implement the Principles of Industry 4.0." *Management and Production Engineering Review* 8 (2): 3–8. doi:10.1515/mper-2017-0012.

Baykasoğlu, A., and K. Subulan. 2016. "A Multi-Objective Sustainable Load Planning Model for Intermodal Transportation Networks with a Real-Life Application." *Transportation Research Part E* 95: 207–247. doi:10.1016/j.tre.2016.09.011.

Beske, P. 2012. "Dynamic Capabilities and Sustainable Supply Chain Management." *International Journal of Physical Distribution & Logistics Management* 42 (4): 372–387. doi:10.1108/09600031211231344.

Beske, P., A. Land, and S. Seuring. 2014. "Sustainable Supply Chain Management Practices and Dynamic Capabilities in the Food Industry: A Critical Analysis of the Literature." *International Journal of Production Economics* 152: 131–143. doi:10.1016/j.ijpe.2013.12.026.

Bibi, F., C. Guillaume, N. Gontard, and B. Sorli. 2017. "A Review: RFID Technology Having Sensing Aptitudes for Food Industry and Their Contribution to Tracking and Monitoring of Food Products." *Trends in Food Science & Technology* 62: 91–103. doi:10.1016/j.tifs.2017.01.013.

Boons, F., and F. Lüdeke-Freund. 2013. "Business Models for Sustainable Innovation: State-of-the-Art and Steps towards a Research Agenda." *Journal of Cleaner Production* 45 (2): 9–19. doi:10.1016/j.jclepro.2012.07.007.

Branke, J., S. S. Farid, and N. Shah. 2016. "Industry 4.0: A Vision for Personalized Medicine Supply Chains?" *Cell and Gene Therapy Insights* 2 (2): 263–270. doi:10.18609/cgti.2016.027.

Bressanelli, G., F. Adrodegari, M. Perona, and N. Saccani. 2018. "Exploring How Usage-Focused Business Models Enable Circular Economy through Digital Technologies." *Sustainability* 10 (3): 639–659. doi:10.3390/su10030639.

Cai, Y., and T. Choi. 2021. "Extended Producer Responsibility: A Systematic Review and Innovative Proposals for Improving Sustainability." *IEEE Transactions on Engineering Management* 68 (1): 272–288. doi:10.1109/TEM.2019.2914341.

Carter, C. R., and P. L. Easton. 2011. "Sustainable Supply Chain Management: Evolution and Future Directions." *International Journal of Physical Distribution & Logistics Management* 41 (1): 46–62. doi:10.1108/09600031111101420.

Carter, C. R., and M. M. Jennings. 2002. "Logistics Social Responsibility: An Integrative Framework." *Journal of Business Logistics* 23 (1): 145–180. doi:10.1002/j.2158-1592.2002.tb00020.x.

Carter, C. R., and D. S. Rogers. 2008. "A Framework of Sustainable Supply Chain Management: Moving toward New Theory." *International Journal of Physical Distribution & Logistics Management* 38 (5): 360–387. doi:10.1108/09600030810882816.

Ciliberti, F., G. de Groot, J. de Haan, and P. Pontrandolfo. 2009. "Codes to Coordinate Supply Chains: SMEs' Experiences with SA8000." *Supply Chain Management* 14 (2): 117–127. doi:10.1108/13598540910941984.

Conde, C. G., and M. L. Martens. 2020. "Six Sigma Project Generation and Selection: Literature Review and Feature Based Method Proposition." *Production Planning & Control* 31 (16): 1303–1312. doi:10.1080/09537287.2019.1706196.

Deloitte. 2017. *Industry 4.0 – Is Africa ready for digital transformation?* Accessed 1 August 2021. https://www2.deloitte.com/content/dam/Deloitte/za/Documents/manufacturing/za-Africa-industry-4.0-report-April14.pdf.

Dev, N., R. Shankar, and S. Swami. 2020. "Diffusion of Green Products in Industry 4.0: Reverse Logistics Issues during Design of Inventory and Production Planning System." *International Journal of Production Economics* 223: 107519. doi:10.1016/j.ijpe.2019.107519.

Defee, C. C., and B. S. Fugate. 2010. "Changing Perspective of Capabilities in the Dynamic Supply Chain Era." *The International Journal of Logistics Management* 21 (2): 180–206. doi:10.1108/09574091011071915.

Denyer, D, and D. Tranfield. 2009. "Producing a Systematic Review." In *The Sage Handbook of Organizational Research Methods*, edited by Buchanan, D., and Bryman, A., 671–689. London: Sage Publications Ltd.

Despeisse, M., M. Baumers, P. Brown, F. Charnley, S. J. Ford, A. Garmulewicz, S. Knowles, et al. 2017. "Unlocking Value for a Circular Economy through 3D Printing: A Research Agenda." *Technological Forecasting and Social Change* 115: 75–84. doi:10.1016/j.techfore.2016.09.021.

Duff, A. 1996. "The Literature Search: A Library-Based Model for Information Skills Instruction." *Library Review* 45 (4): 14–18. doi:10.1108/00242539610115263.

El-Kassar, A.-N., and S. K. Sigh. 2018. "Green Innovation and Organizational Performance: The Influence of Big Data and the Moderating Role of Management Commitment and HR Practices." *Technological Forecasting & Social Change* 144: 16. doi:10.1016/j.techfore.2017.12.016.

Ellen MacArthur Foundation. 2017. "Intelligent Assets: Unlocking the Circular Economy Potential." Accessed 18 January 2019. https://www.ellenmacarthurfoundation.org/assets/downloads/publications/EllenMacArthurFoundation_Intelligent_Assets_080216.pdf

Ellen MacArthur Foundation. 2018. *What is a Circular Economy?* Accessed 18 January 2019. https://www.ellenmacarthurfoundation.org/circular-economy/concept

Ellen MacArthur Foundation. 2012. "Towards the Circular Economy vol. 1: An Economic and Business Rationale for An Accelerated Transition." 25 January. Accessed 31 May 2018. https://www.ellenmacarthurfoundation.org/publications/towards-the-circular-economy-vol-1-an-economic-and-business-rationale-for-an-accelerated-transition, [Accessed on 31 May 2018].

Esposito, M., T. Tse, and K. Soufani. 2018. "Introducing a Circular Economy: New Thinking with New Managerial and Policy Implications." *California Management Review* 60 (3): 5–19. doi:10.1177/%2F0008125618764691.

Fang, C., X. Liu, J. Pei, W. Fan, and P. M. Pardalos. 2016. "Optimal Production Planning in a Hybrid Manufacturing and Recovering System Based on the Internet of Things with Closed Loop Supply Chains." *Operational Research* 16 (3): 543–577. doi:10.1007/s12351-015-0213-x.

Fatorachian, H., and H. Kazemi. 2018. "A Critical Investigation of Industry 4.0 in Manufacturing: Theoretical Operationalisation Framework." *Production Planning & Control* 29 (8): 633–644. doi:10.1080/09537287.2018.1424960.

Franco, M. A. 2017. "Circular Economy at the Micro Level: A Dynamic View of Incumbents' Struggles and Challenges in the Textile Industry." *Journal of Cleaner Production* 168: 833–845. doi:10.1016/j.jclepro.2017.09.056.

Friday, D., S. Ryan, R. Sridharan, and D. Collins. 2018. "Collaborative Risk Management: A Systematic Literature Review." *International Journal of Physical Distribution & Logistics Management* 48 (3): 231–253. doi:10.1108/IJPDLM-01-2017-0035.

Fussler, C, and P. James. 1996. *Driving Eco-Innovation: A Breakthrough Discipline for Innovation and Sustainability*. Hoboken: Financial Times/Prentice Hall.

Gates, D. 2017. "Industry 4.0: Scaling up to Success." Accessed 5 May 2018. https://home.kpmg.com/uk/en/home/insights/2017/04/industry-4-0-scaling-up-to-success.html.

Gao, D., Z. Xu, Y. Z. Ruan, and H. Lu. 2017. "From a Systematic Literature Review to Integrated Definition for Sustainable Supply Chain Innovation (SSCI)." *Journal of Cleaner Production* 142: 1518–1538. doi:10.1016/j.jclepro.2016.11.153.

Geissdoerfer, M., D. Vladimirova, and S. Evans. 2018. "Sustainable Business Model Innovation: A Review." *Journal of Cleaner Production* 198: 401–416. doi:10.1016/j.jclepro.2018.06.240.

Ghisellini, P., C. Cialani, and S. Ulgiati. 2016. "A Review on Circular Economy: The Expected Transition to a Balanced Interplay of Environmental and Economic Systems." *Journal of Cleaner Production* 114 (15): 11–32. doi:10.1016/j.jclepro.2015.09.007.

Golicic, S. L., and C. D. Smith. 2013. "A Meta-Analysis of Environmentally Sustainable Supply Chain Management Practices and Firm Performance." *Journal of Supply Chain Management* 49 (2): 78–95. doi:10.1111/jscm.12006.

Govindan, K., and M. Hasanagic. 2018. "A Systematic Review on Drivers, Barriers, and Practices Towards Circular Economy: A Supply Chain Perspective." *International Journal of Production Research* 56 (1-2): 278–311. doi:10.1080/00207543.2017.1402141.

Henley, W. 2013. "The Circular Economy: Could It Present A New Way of Doing Business?" *The Guardian*. Accessed 3 May 2018. https://www.theguardian.com/sustainable-business/circular-economy-new-way-doing-business.

Helfat, C. E. 2007. *Dynamic Capabilities: Understanding Strategic Change in Organizations*. Malden, MA: Blackwell Publications.

Hofmann, E., and M. Rüsch. 2017. "Industry 4.0 and the Current Status as Well as Future Prospects on Logistics." *Computers in Industry* 89: 23–34. doi:10.1016/j.compind.2017.04.002.

Hopp, W. J. 2004. "Ten Most Influential Papers of Management Science's First Fifty Years." *Management Science* 50 (12_supplement): 1763–1763. doi:10.1287/mnsc.1040.0299.

Iacovidou, E., P. Purnell, and M. K. Lim. 2018. "The Use of Smart Technologies in Enabling Construction Components Reuse: A Viable Method or a Problem Creating Solution?" *Journal of Environmental Management* 216: 214–223. doi:10.1016/j.jenvman.2017.04.093.

Jabbour, C. J. C., A. B. L. de Sousa Jabbour, J. Sarkis, and M. C. Filho. 2017. "Unlocking the Circular Economy through New Business Models Based on Large-Scale Data: An Integrative Framework and Research Agenda." *Technological Forecasting & Social Change*. *144*: 546–552. doi:10.1016/j.techfore.2017.09.010.

Lopes de Sousa Jabbour, Ana Beatriz, Charbel Jose Chiappetta Jabbour, Moacir Godinho Filho, and David Roubaud. 2018. "Industry 4.0 and the Circular Economy: A Proposed Research Agenda and Original Roadmap for Sustainable Operations." *Annals of Operations Research* 270 (1–2): 273–286. doi:10.1007/s10479-018-2772-8.

Jose, R., and S. Ramakrishna. 2018. "Materials 4.0: Materials Big Data Enabled Materials Discovery." *Applied Materials Today* 10: 127–132. doi:10.1016/j.apmt.2017.12.015.

Kagermann , H. W. Wahlster, and J. Helbig. 2013. "Recommendations for Implementing the Strategic Initiative INDUSTRIE 4.0 – Final Report of the Industrie 4.0 Working Group." Accessed 10 January 2019. file:///C:/Users/gzhao1/Downloads/Final_report__Industrie_4.0_accessibl e.pdf

Kähkönen, A.-K., K. Lintukangas, and J. Hallikas. 2018. "Sustainable Supply Management Practices: Making a Difference in a Firm's Sustainability Performance." *Supply Chain Management* 23 (6): 518–530. doi:10.1108/SCM-01-2018-0036.

Kang, Hyoung Seok, Ju Yeon Lee, Sang Su Choi, Hyun Kim, Jun Hee Park, Ji Yeon Son, Bo Hyun Kim, and Sang Do Noh. 2016. "Smart Manufacturing: Past Research, Present Findings, and Future Directions." *International Journal of Precision Engineering and Manufacturing-Green Technology* 3 (1): 111–128. doi:10.1007/s40684-016-0015-5.

Kitcharoen, K. 2004. "The Importance-performance Analysis of Service Quality in Administrative Departments of Private Universities in Thailand." *ABAC Journal* 24 (3): 20–46.

Kristoffersen, E., F. Blomsma, P. Mikalef, and J. Li. 2020. "The Smart Circular Economy: A Digital-Enabled Circular Strategies Framework for Manufacturing Companies." *Journal of Business Research* 120: 241–261. doi:10.1016/j.jbusres.2020.07.044.

Kouhizadeh, M., Q. Zhu, and J. Sarkis. 2020. "Blockchain and the Circular Economy: Potential Tensions and Critical Reflections from Practice." *Production Planning & Control* 31 (11–12): 950–966. doi:10.1080/09537287.2019.1695925.

Kuo, T.-C., and S. Smith. 2018. "A Systematic Review of Technologies Involving Eco-Innovation for Enterprises Moving towards Sustainability." *Journal of Cleaner Production* 192: 207–220. doi:10.1016/j.jclepro.2018.04.212.

Kuznetsova, E., E. Zio, and R. Farel. 2016. "A Methodological Framework for Eco-Industrial Park Design and Optimization." *Journal of Cleaner Production* 126: 308–324. doi:10.1016/j.jclepro.2016.03.025.

Lambert D. M., K. L. Croxton, S. J. Garcı´a-Dastugue, M. Knemeyer, and D. S. Rogers. 2006. *Supply Chain Management Processes, Partnerships, Performance*, 3rd ed. Jacksonville, FA: The Hartley Press Inc.

Lewandowski, M. 2016. "Designing the Business Models for Circular Economy – Towards the Conceptual Framework." *Sustainability* 8 (1): 43–70. doi:10.3390/su8010043.

Liao, Y., F. Deschamps, E. D. F. R. Loures, and L. F. P. Ramos. 2017. "Past, Present and Future of Industry 4.0 – A Systematic Literature Review and Research Agenda Proposal." *International Journal of Production Research* 55 (12): 3609–3629. doi:10.1080/00207543.2017.1308576.

Liboni, L. B., L. H. B. Liboni, and L. O. Cezarino. 2018. "Electric Utility 4.0: Trends and Challenges towards Process Safety and Environmental Protection." *Process Safety and Environmental Protection* 117: 593–605. doi:10.1016/j.psep.2018.05.027.

Lu, H., A. Potter, V. S. Rodrigues, and H. Walker. 2018. "Exploring Sustainable Supply Chain Management: A Social Network Perspective." *Supply Chain Management* 23 (4): 257–277. doi:10.1108/SCM-11-2016-0408.

Luthra, S., and S. K. Mangla. 2018. "Evaluating Challenges to Industry 4.0 Initiatives for Supply Chain Sustainability in Emerging Economies." *Process Safety and Environmental Protection* 117: 168–179. doi:10.1016/j.psep.2018.04.018.

Mladineo, Marko, Stipo Celar, Luka Celent, and Marina Crnjac. 2018. "Selecting Manufacturing Partners in Push and Pull-Type Smart Collaborative Networks." *Advanced Engineering Informatics* 38: 291–305. doi:10.1016/j.aei.2018.08.001.

Melacini, M., S. Perotti, M. Rasini, and E. Tappia. 2018. "E-Fulfilment and Distribution in Omni-Channel Retailing: A Systematic Literature Review." *International Journal of Physical Distribution & Logistics Management* 48 (4): 391–414. doi:10.1108/IJPDLM-02-2017-0101.

Morali, O., and C. Searcy. 2013. "A Review of Sustainable Supply Chain Management Practices in Canada." *Journal of Business Ethics* 117 (3): 635–658. doi:10.1007/s10551-012-1539-4.

Moreno, Mariale, Richard Court, Matt Wright, and Fiona Charnley. 2019. "Opportunities for Redistributed Manufacturing and Digital Intelligence as Enablers of a Circular Economy." *International Journal of Sustainable Engineering* 12 (2): 77–94. doi:10.1080/19397038.2018.1508316.

Mukherjee, Archana A., Rajesh Kumar Singh, Ruchi Mishra, and Surajit Bag. 2021. "Application of Blockchain Technology for Sustainability Development in Agricultural Supply Chain: justification Framework." *Operations Management Research 2021*: 5. doi:10.1007/s12063-021-00180-5.

Nascimento, D. L. M., V. Alencastro, O. L. G. Quelhas, R. G. G. Caiado, J. A. Garza-Reyes, L. Rocha-Lona, and G. Tortorella. 2019. "Exploring Industry 4.0 Technologies to Enable Circular Economy Practices in a Manufacturing Context: A Business Model Proposal." *Journal of Manufacturing Technology Management* 30 (3): 607–627. doi:10.1108/JMTM-03-2018-0071.

Nobre, G. C., and E. Tavares. 2017. "Scientific Literature Analysis on Big Data and Internet of Things Applications on Circular Economy: A Bibliometric Study." *Scientometrics* 111 (1): 463–492. doi:10.1007/s11192-017-2281-6.

Pagell, M., and Z. Wu. 2009. "Building a More Complete Theory of Sustainable Supply Chain Management Using Case Studies of 10 Exemplars." *Journal of Supply Chain Management* 45 (2): 37–56. doi:10.1111/j.1745-493X.2009.03162.x.

Pan, S.-Y., M. Gao, H. Kim, K. J. Shah, S.-L. Pei, and P.-C. Chiang. 2018. "Advances and Challenges in Sustainable Tourism toward a green economy." *The Science of the Total Environment* 635: 452–469. doi:10.1016/j.scitotenv.2018.04.134.

Parreno-Marchante, A., A. Alvarez-Melcon, M. Trebar, and P. Filippin. 2014. "Advanced Traceability System in Aquaculture Supply Chain." *Journal of Food Engineering* 122: 99–109. doi:10.1016/j.jfoodeng.2013.09.007.

Papadopoulos, T., P. S. Singh, K. Spanaki, A. Gunasekaran, and R. Dubey. 2022. "Towards the Next Generation of Manufacturing: Implications of Big Data and Digitalization in the Context of Industry 4.0." *Production Planning & Control* 33 (2–3): 101–104. doi:10.1080/09537287.2020.1810767.

Peng, T., K. Kellens, R. Tang, C. Chen, and G. Chen. 2018. "Sustainability of Additive Manufacturing: An Overview on Its Energy Demand and Environmental Impact." *Additive Manufacturing* 21: 694–704. doi:10.1016/j.addma.2018.04.022.

PwC. 2021. "Industry 4.0 – South African Perspective." Accessed 01 August 2021. https://www.pwc.co.za/en/publications/industry-40.html.

Qiao, F., J. Liu, and Y. Ma. 2021. "Industrial Big-Data-Driven and CPS-Based Adaptive Production Scheduling for Smart Manufacturing." *International Journal of Production Research* 59 (23): 7139–7159. doi:10.1080/00207543.2020.1836417.

Ramakrishna, S., A. Ngowi, H. Jager, and B. Awuzie. 2020. "Emerging Industrial Revolution: Symbiosis of Industry 4.0 and Circular Economy: The Role of Universities." *Science, Technology and Society* 25 (3): 505–525. doi:10.1177/0971721820912918.

Rehman, M. H., V. Chang, A. Batool, and T. Y. Wah. 2016. "Big Data Reduction Framework for Value Creation in Sustainable Enterprises." *International Journal of Information Management* 36 (6): 917–928. doi:10.1016/j.ijinfomgt.2016.05.013.

Rogetzer, Patricia, Lena Silbermayr, and Werner Jammernegg. 2019. "Sustainable Sourcing Including Capacity Reservation for Recycled Materials: A Newsvendor Framework with Price and Demand Correlations." *International Journal of Production Economics* 214: 206–219. doi:10.1016/j.ijpe.2019.03.014.

Saenz, M. J., and X. Koufteros. 2015. "Special Issues on Literature Reviews in Supply Chain Management and Logistics." *International Journal of Physical Distribution & Logistics Management* 45 (1/2): 1–8. doi:10.1108/IJPDLM-12-2014-0305.

Sarkis, J. 2001. "Manufacturing's Role in Corporate Environmental sustainability – Concerns for the New Millennium." *International Journal of Operations & Production Management* 21 (5/6): 666–686. doi:10.1108/01443570110390390.

Schaltegger, S., F. Lüdeke-Freund, and E. G. Hansen. 2012. "Business Cases for Sustainability: The Role of Business Model Innovation for Corporate Sustainability." *International Journal of Innovation and Sustainable Development* 6 (2): 95–119. doi:10.1504/IJISD.2012.046944.

Seuring, S., and M. Müller. 2008. "From a Literature Review to a Conceptual Framework for Sustainable Supply Chain Management." *Journal of Cleaner Production* 16 (15): 1699–1710. doi:10.1016/j.jclepro.2008.04.020.

Seuring, S., and S. Gold. 2012. "Conducting Content-snalysis Based Literature Reviews in Supply Chain Management." *Supply Chain Management: An International Journal* 17 (5): 544–555. doi:10.1108/13598541211258609.

Shamsuzzoha, A., C. Toscano, L. M. Carneiro, V. Kumar, and P. Helo. 2016. "ICT Based Solution Approach for Collaborative Delivery of Customised Products." *Production Planning & Control* 27 (4): 280–298. doi:10.1080/09537287.2015.1123322.

Sjodin, R. D., V. Parida, M. Leksell, and A. Petrovic. 2018. "Smart Factory Implementation and Process Innovation." *Research-Technology Management* 61 (5): 22–31. doi:10.1080/08956308.2018.1471277.

Stock, T., and G. Seliger. 2016. "Opportunities of Sustainable Manufacturing in Industry 4.0." *Procedia CIRP* 40: 536–541. doi:10.1016/j.procir.2016.01.129.

Su, B., A. Heshmati, Y. Geng, and X. Yu. 2013. "A Review of the Circular Economy in China: Moving from Rhetoric to Implementation." *Journal of Cleaner Production* 42 (3): 215–227. doi:10.1016/j.jclepro.2012.11.020.

Teece, D. J., G. Pisano, and A. Shuen. 1997. "Dynamic Capabilities and Strategic Management." *Strategic Management Journal* 18 (7): 509–533. doi:10.1002/(SICI)1097-0266(199708)18:7<509::AID-SMJ882>3.0.CO;2-Z.

Telukdarie, A., E. Buhulaiga, S. Bag, S. Gupta, and Z. Luo. 2018. "Industry 4.0 Implementation for Multinationals." *Process Safety and Environmental Protection* 118: 316–329. doi:10.1016/j.psep.2018.06.030.

Tolio, T., A. Bernard, M. Colledani, S. Kara, G. Seliger, J. Duflou, O. Battaia, and S. Takata. 2017. "Design, Management and Control of Demanufacturing and Remanufacturing Systems." *CIRP Annals* 66 (2): 585–609. doi:10.1016/j.cirp.2017.05.001.

Touboulic, A., and H. Walker. 2015. "Theories in Sustainable Supply Chain Management: A Structured Literature Review." *International Journal of Physical Distribution & Logistics Management* 45 (1/2): 16–42. doi:10.1108/IJPDLM-05-2013-0106.

Tranfield, D., D. Denyer, and P. Smart. 2003. "Towards a Methodology for developing evidence-Informed Management Knowledge by Means of Systematic Review." *British Journal of Management* 14 (3): 207–222. doi:10.1111/1467-8551.00375.

Tsai, W., and S. Lai. 2018. "Green Production Planning and Control Model with ABC under Industry 4.0 for the Paper Industry." *Sustainability* 10 (8): 2932. doi:10.3390/su10082932.

Tseng, M.-L., R. R. Tan, A. S. F. Chiu, C.-F. Chien, and T. C. Kuo. 2018. "Circular Economy Meets Industry 4.0: Can Big Data Drive Industrial Symbiosis?" *Resources Conservation & Recycling* 131: 146–147. doi:10.1016/j.resconrec.2017.12.028.

UNIDO. 2017. "New UNIDO Report Explores Potential of Industry 4.0 to Accelerate Transition Towards Sustainable Energy." 30 August. Accessed 31 May 2018. https://www.unido.org/news/new-unido-report-explores-potential-industry-40-accelerate-transition-towards-sustainable-energy. [Accessed 31 May 2018].

Urbinati, A., D. Chiaroni, and V. Chiesa. 2017. "Towards a New Taxonomy of Circular Economy Business Models." *Journal of Cleaner Production* 168: 487–498. doi:10.1016/j.jclepro.2017.09.047.

Verdouw, C. N., R. M. Robbemond, T. Verwaart, J. Wolfert, and A. J. M. Beulens. 2018. "A Reference Architecture for IoT-Based Logistic Information Systems in Agri-Food Supply Chains." *Enterprise Information Systems* 12 (7): 755–779. doi:10.1080/17517575.2015.1072643.

Wang, D., and Y. Zhang. 2020. "Implications for Sustainability in Supply Chain Management and the Circular Economy Using Machine Learning Model." *Information System E-Business Manage* 2020: 1. doi:10.1007/s10257-020-00477-1.

Walker, H. 2014. "Sustainable Operations Management: Recent Trends and Future Directions [Editorial]." *International Journal of Operations and Production Management* 34 (5): e0557. 10.1108/IJOPM-12-2013-0557

Waste and Resources Action Programme. 2018. Accessed 03 May 2018. http://www.wrap.org.uk. [Accessed 3 May 2018].

Winter, M., and A. M. Knemeyer. 2013. "Exploring the Integration of Sustainability and Supply Chain Management: Current State and Opportunities for Future Inquiry." *International Journal of Physical Distribution & Logistics Management* 43 (1): 18–38. doi:10.1108/09600031311293237.

Yang, Shanshan., Aravind. M. R, Jacek. Kaminski, and Helene. Pepin. 2018. "Opportunities for Industry 4.0 to Support Remanufacturing." *Applied Sciences* 8 (7): 1177. doi:10.3390/app8071177.

Zailani, S., K. Jeyaraman, G. Vengadasan, and R. Premkumar. 2012. "Sustainable Supply Chain Management (SSCM) in Malaysia: A Survey." *International Journal of Production Economics* 140 (1): 330–340. doi:10.1016/j.ijpe.2012.02.008.

Zhang, Y., S. Ren, Y. Liu, T. Sakao, and D. Huisingh. 2017. "A Framework for Big Data Driven Product Lifecycle Management." *Journal of Cleaner Production* 159: 229–240. doi:10.1016/j.jclepro.2017.04.172.