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Integrating circular economy and industry 4.0 into sustainable supply chain management: a dynamic capability view

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Integrating circular economy and industry 4.0 into sustainable supply chain management: a dynamic capability view

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1. Introduction

Mainly driven by the external pressures such as market and regulation, customer demands and external stakeholders' requirements (Morali and Searcy 2013; Sarkis 2001; Lu et al., 2018), sustainability is argued to be integrated in key business processes in supply chain management (SCM) (Lambert et al. 2006; Ciliberti et al. 2008; Pagell and Wu 2009). Building on Elkington's (1998) work of the triple bottom line (TBL) and other logistics literature, Carter and Rogers (2008) suggested an organisation should be economically viable, environmentally friendly and socially responsible and defined sustainable SCM (SSCM) as the "*strategic, transparent integration and achievement of an organisation's social, environmental, and economic goals in the systemic coordination of key inter-organisational business processes for improving the long-term economic performance of the individual company and its supply chains*" (Carter and Rogers 2008:368). It is argued environmental and social goals need to be achieved in the supply chain and competitiveness is expected to be maintained by meeting customer requirements and relevant economic criteria (Seuring and Muller 2008).

SSCM has been diffused and integrated into the SCM practices, such as environmental purchasing, sustainable warehousing and packaging, are widely implemented by organisations in various industries (Carter and Jennings 2002; Zailani et al. 2012). Empirical results demonstrate the adoption of SSCM practices can help organisations reduce waste emission, create green image in the marketplace, increase job satisfaction, improve operational efficiency and achieve better financial performance (Baykasoglu and Subulan 2016; Golicic and Smith 2013; Kähkönen et al. 2018). Recent literature reviews show that research on SSCM has extended to aligning sustainability with other emerging practices, for example, circular economy (CE), digital and supply chain innovation (Gao et al. 2017; Geissdoerfer et al. 2018; Telukdarie et al. 2018).

Circular economy (CE), a recently emerged industrial paradigm (Ellen MacArthur Foundation, 2012), proposes a new perspective to business innovation through organisational and operational systems of production and consumption (Lopes de Sousa Jabbour et al., 2018). One of the perspectives of CE is focused on a circular approach to energy and materials for providing economic, environmental, and social benefits of triple bottom line (Geissdoerfer et al. 2017). CE reconciles the outlook for a nation's economic growth with environmental and social benefits, while, at enterprise level, it aims to create superior value (Henley, 2013). CE addresses some of the issues of ecological degradation and resource scarcity in a business context (Su et al., 2013; Vladimirova, 2017; Mangla et al., 2018).

Industry 4.0, the "Fourth Industrial Revolution" (UNIDO, 2017), is adopted as modern technology enablers to enhance industry's performance (Gates, 2017) with concerted effort of technologies (e.g. Big Data, IoT and digitisation, etc.) approaches, methodologies, and operational capabilities. However, appropriate alignment of the Industry 4.0 initiatives and the enterprises' long-term strategic objectives is essential to enhance overall performance (Gates, 2017) of a supply chain. For example, manufacturing firms like Caterpillar (Caterpillar Energy Solutions GmbH, 2017) and Renault, etc. have adopted Industry 4.0 to enhance their efficiency and reduce costs. BMW, Jaguar Land Rover, Rolls-Royce, GE and Philips, etc. have implemented Industry 4.0. In the food sector, for example, Mondelez, the owner of many prominent brands like Cadbury, Milka, Oreo and Toblerone etc., at their Global Centre of Excellence for chocolate in Bournville, UK, has adopted Industry 4.0 based smarter factories (Mondelez International, 2017) aiming to improve process efficiency in their supply chains through manufacturing/packaging wastes reduction and productivity improvement.

Drawing on the current research gap and industrial values, this research will contribute to build a conceptual model, integrating CE and Industry 4.0 in SSCM for improving sustainability practice. In this sense, we aim to address following research question:

RQ: How circular economy and industry 4.0 can integrate to improve sustainable supply chain management (SSCM)?

This research is positioned in six sections. Section 1 presents the research background and discusses on the research question. Section 2 speaks for relevant literature for this work. Section 3 portrays the designed research methodology. Section 4 presents the data analysis and results. In Section 5, the conceptual framework will be built, drawing from the use of dynamic capability theory and the research findings in section 4. To end, conclusions, along with contributions for academic theory and industrial practice are summarized in Section 6.

2. Literature review

2.1 Circular economy

Circular economy (CE) has become a popular topic primarily advocated by governmental organisations and business agencies in recent years. For instance, China has adopted a law to promote the use of CE practices since 2009 and later European Commission has launched an action plan to develop CE initiatives (EEA 2015; NPC 2008). The spread of the CE concept is underpinned by the concerns of the linear "take-make-dispose" dominant economic model, which is described as using natural resources to create mass-produced goods and disposing these goods after a single use (Ellen MacArthur Foundation 2018). It reaches a consensus that this prevailing linear model challenges the physical limits of the Earth's natural resources and threatens the sustainable development of our economy. In this sense, CE which emphasises sustainable production and consumption is considered as a viable model to enable continually reusing products and materials, and using renewable resources (Urbinati, Chiaroni, and Chiesa 2017; Esposito, Tse, and Soufani 2018).

Multiple research has been conducted to investigate the CE concept by both practitioners and academics. For practitioners, the CE concept is mainly popularised by Ellen MacArthur Foundation as "*an economy that is restorative and regenerative by design*" (Ellen MacArthur Foundation 2017:19). It is based on three principles, namely, design out waste and pollution, keep products and materials in use and regenerate natural systems (Ellen MacArthur Foundation 2018). Hence, a transition to the CE not only provides environmental benefits such as reduction of production waste, but also generates social and economic benefits such as net material savings and job creation potential (Schaltegger, Lüdeke-Freund, Hansen 2012; Boons and Lüdeke-Freund 2013). For academics, different definitions of CE have been provided by the extant literature. Some researchers develop CE definition on the basis of Ellen MacArthur Foundation's work (e.g. Singh and Ordonez 2016; Moreau et al. 2017) whereas a number of researchers relate CE concept to their own research background (e.g. Ma et al. 2015). Korhonen et al. (2018) argue that CE has already become an essentially contested concept as this concept is open to revision and internally complex with various descriptions. Similarly, Homrich et al. (2018) point out the CE concept comes from different schools of thoughts and thereby, the extant literature lacks a convergence on the CE definition. Instead of giving a structured and unified definition, Korhonen et al. (2018:547) suggest a working definition of CE as "*a sustainable development initiative with the objective of reducing the societal production-consumption systems' linear material and energy throughput flows by applying materials cycles, renewable and cascade-type energy flows to the linear system*". It implies the implementation of CE concept requires the cooperation of all the supply chain members such as manufacturers and customers as well as other societal actors through slowing, closing, and narrowing resource loops (Bocken et al. 2016).

Empirical research shows the CE concept can be implemented at three levels, including eco-regions at the macro-level, eco-industrial parks at the meso-level, and eco-enterprises at the micro-level (Yuan, Bi, and Moriguichi 2006). CE practices associated with areas of production, consumption, waste management and other support are adopted across these three levels (Zhu, Geng, and Lai 2010; Su et al. 2013). Institutional pressures, including government regulations and policy documents issued by non-governmental organisations, serve as the main driver to the adoption of CE practices (Zeng et al. 2017). Other factors such as top management commitment, employee involvement and customer awareness are also acknowledged as the enablers to CE practices (Siemieniuch, Sinclair, and Henshaw 2015; Moktadir et al.2018). With the rapid development of digital technologies, the use of intelligent assets (a key feature of Industry 4.0) has been recognised as another enabler to unlock the CE potential, for example, tracking products consumption in order to recover components (Ellen MacArthur Foundation 2017; Jabbour et al. 2018).

2.2 Industry 4.0

From a technological evolution perspective, the development of industrialisation is moving towards the fourth industrial revolution (also known as Industry 4.0) with application of modern information and communication technologies and connected with integration of industry automation, data networks, and contemporary manufacturing technologies (Basl 2017; Luthra and Mangla 2018). While the first three industrial revolutions are viewed as the results of mechanisation, electricity and information technology (IT), the introduction of the Internet of Things (IoT) and Cyber-Physical Systems (CPS) into the manufacturing environment is ushering in the fourth industrial revolution (Kagermann, Wahlster, and Helbig 2013).

As the global leader in the manufacturing equipment sector, Germany is the pioneer in this transformation by passing the "High-Tech Strategy 2020" action plan in 2012 and launching the project named "Industrie 4.0". The use of Industry 4.0 related technologies including 3D printing, CPS, IoT and cloud manufacturing is expected to facilitate fundamental improvements of industrial processes embedded in product design, manufacturing and delivery, and enable the establishment of smart factories (Kagermann, Wahlster, and Helbig 2013; Kang et al. 2016). 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 UK and South Korea also present their long-term governmental plans for the manufacturing sector to ensure they can 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 has been addressed by several researchers. Branke et al. (2016) indicate that the typical scenario of Industry 4.0 is the self-organising 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) note 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. de Sousa Jabbour et al. (2018) and Stock and Seliger (2016) highlight the sustainability implications of Industry 4.0, including the optimal use of resources, reduction of resources consumption and improvements of productivity. However, challenges to Industry 4.0 for supply chain sustainability have also been identified. These challenges cover legal and ethical issues, organisational issues, strategic and technological issues (Luthra and Mangla 2018; Khan et al. 2017). According to Hofmann and Rüsch (2017), Industry 4.0 is still at its very beginning and it is worth exploring enormous potentials that Industry 4.0 may provide in the area of supply chain and logistics management.

As noticed by Jabbour et al. (2018), some research has started to examine the relationship between CE and Industry 4.0. It is argued that the adoption of Industry 4.0 technologies may facilitate the application of CE principles in operations and SCM (Ellen MacArthur Foundation 2017; Jabbour et al. 2018). However, most studies still discuss these two concepts separately and thereby, it calls for a more overarching view to investigate the connection between CE and Industry 4.0, and addresses their implications to supply chain sustainability.

3. Research methodology

A systematic literature review (SLR) was selected as the research method for this study to detect existing gaps in the scientific literatures, synthesize existing knowledge, create new knowledge and generalize findings (Lagorio et al. 2016). The method employs a series of rigorous and transparent techniques to exhaustively and comprehensively search relevant studies in a way that allow minimizing bias and error, and overcoming drawbacks associated with single studies (Cook et al. 1997; Saenz and Koufteros. 2015; Friday et al. 2018; Melacini et al. 2018). It is a valuable methodology to investigate the intersections of CE and Industry 4.0 in the context of SSCM.

A five-step research methodology proposed by Denyer and Tranfield (2009) would be adopted in this study. In order to reduce bias during the research, a group of three experienced researchers and librarians would be involved in the process of searching databases to avoid limiting itself to specific publications. The detailed description of each step is outlined in the following sub-sections.

3.1 Question formulation

To develop a clear focus of the study, reflected on the overall research question addressed above, three well specified and informative questions are formulated as:

- What are the main applications related to the CE and Industry 4.0 in the context of SSCM?
- What are the key drivers and barriers for applying CE and Industry 4.0 related applications in the SSCM?
- What are the research gaps and future research directions for applying the CE and Industry 4.0 related applications in the context of SSCM?

3.2 Locating studies

This step involves of searching relevant databases to build a comprehensive list of core contributions pertinent to the review questions while minimising the number of irrelevant literatures (Duff. 1996; Denyer and Tranfield. 2009). In order to reduce bias, a panel of experts from China, India, and United Kingdom conducted several brainstorming sessions through skype meetings to discuss keywords and relevant articles. In particular, the ISI Web of Science and Scopus was selected as the source of research because these two databases have some of largest repositories of business research and are typically used in literature reviews (Hope. 2004; Carter and Easton. 2011; Melacini et al. 2018). Since the aim of this research is to identify main issues related to the CE and Industry 4.0 in the context of sustainable operations and SCM, therefore, four categories of keywords were defined to search for studies:

- Words related to sustainable such as sustainab*, green, environment*, ethic*, responsib*, triple-bottom-line, ecol*;

- Words related to CE such as closed-loop, reduction, reuse, recycle;
- Words related to industry 4.0 such as autonomous, automation, technology, and smart;
- Words related to operations and SCM such as supply chain, purchasing, procurement, operations, logistics, production, and transport.

As an example, a full list of keywords used for searching papers in two databases is shown in the Table 1. The search were based on all possible combinations of the four categories of keywords, using the "Topic" field to search. Simultaneously, cross-referencing is necessary in this stage in order to find potential papers that had not been selected from the above mentioned databases (Marchet et al. 2014; Hehenstein et al. 2015). Thus, the initial search presented a total of 504 papers from ISI Web of Science and 455 papers from Scopus.

--Insert Table 1 here ---------------------------------

3.3 Study selection and evaluation

After the first two stages, the articles were entered into a detailed analysis to distinguish the paper relevant or irrelevant to the topic. Tranfield et al. (2003) suggested that it is better to involve more than one reviewer in this stage. Based on the discussions among the three authors, a list of inclusion criteria were chosen to include or exclude papers (see Table 2). For ensuring a certain level of quality, only papers have been published in international peer-review journals can be selected for analysing (Touboulic and Walker. 2015). Simultaneously, to ensure the process of SLR rigorous and transparent, and to reduce any subjective bias and enhance validity, each paper were checked independently by three authors in a blind procedure. Papers that we felt were irrelevant to the CE and Industry 4.0 in the context of sustainable operations and SCM were eliminated. Furthermore, if there was disagreement among the three authors, the fourth author would be involved in the discussions. Using this procedure, 31 papers were selected.

--Insert Table 2 here ---------------------------------

Finally, all selected papers were read entirely by the same three authors independently. By cross-referencing all the citations and bibliographies and talking with experts in the field, another 9 papers were identified, which results 40 peer-reviewed journal papers were found to specifically address the topic of CE and industry 4.0 in the context of sustainable operations and SCM. The selection process is shown in Figure 1.

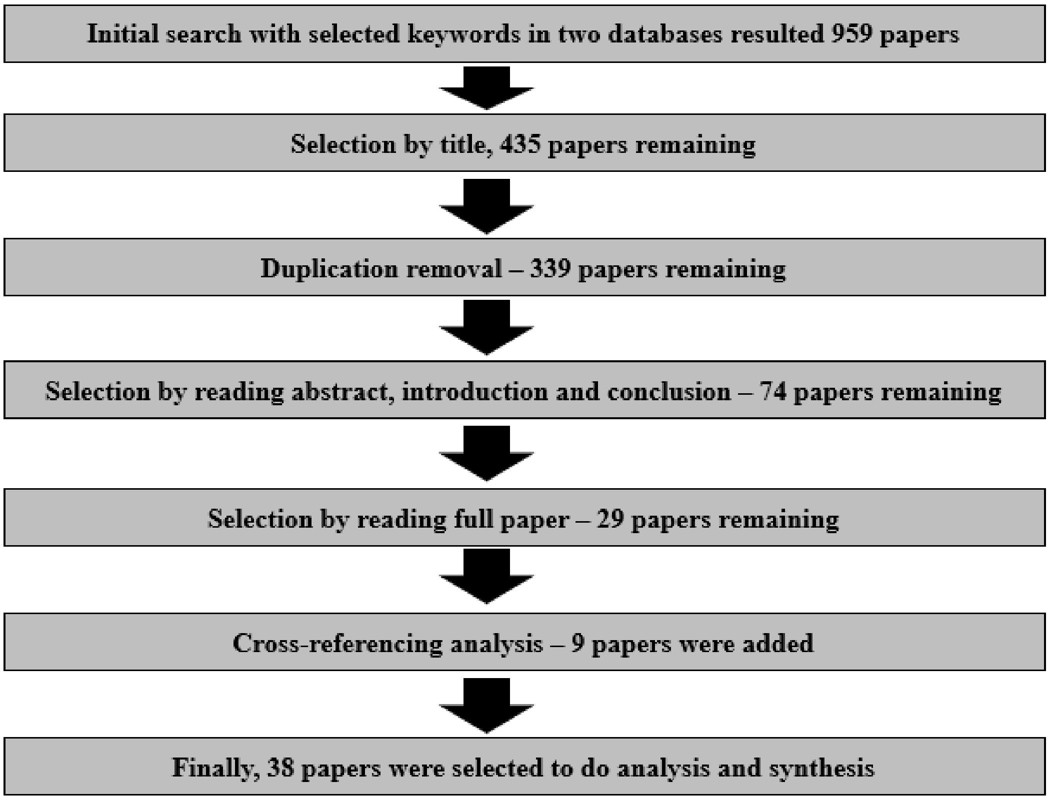

Figure 1 The selection process of papers

3.4 Analysis and synthesis

After collecting the most relevant papers to be entered into Microsoft Excel spreadsheet, the articles were entered into in-depth analysis and synthesis. 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, p.685). Therefore, the criteria for grouping studies based on the general information of the studies such as the date of publication, location, methodology used, and the theory adopted (see Table 3).

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As for the thematic scope, by conducting brainstorming sessions with the authors who involved in finding relevant literature and discussing the evidence that had emerged from literature with experts, two key themes has been identified:

(1) The applications of industry 4.0 technology have been applied in the CE in the context of sustainable operations and SCM such as big data, internet of things (IoT), and additive manufacturing.

(2) The challenges for applying big data, IoT and additive manufacturing in the context

of sustainable operations and SCM.

3.5 Reporting and using the results

After analysing and synthesising of all papers, the emerging evidence is elaborated, that is, reporting and using the results. Therefore, the general information of the studies and the main issues related CE and industry 4.0 in the context of sustainable operations and SCM will be descripted and discussed in the next section.

4. Drivers and barriers for integrating CE and Industry 4.0 in SSCM

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., 2018, p.3) which creates better understanding for 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 supply chain management, the systemic operation and stakeholder collaboration.

Information system and technology: According to Verdouw et al. (2018), the information system supports the intelligent analysis and data sharing. The current use of technologies, such as barcodes, radio frequency identification (RFID) and WSN in logistics and operations system essentially enhance real-time information collection for supply chain monitor and improvement (Bibi et al. 2017; Parreno-Marchante et al., 2014; Fang, 2015). 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 on sustainability issues in supply chain operations (Iacovidou, Purnell and Lim, 2017). The efficient use of innovative technology dramatically increases the breadth and depth of data analysis to understand the behavioral changes in operations and sustainability practices (Yang et al., 2018).

Systemic operations is highly related to product design, manufacturing and processes for sustainable supply chain operations. The design of products that consume less raw materials and hazardous pollutants, extend life span and minimize waste in the early stage can increase the possibility of reuse, recycle and remanufacture end-used components in the later disassembled stage (Jabbour et al., 2018). Besides, 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). Furthermore, the high level of connectivity in Industry 4.0 allows managers to analyse potential limitation and optimize operational efficiency, driving for 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).

Stakeholder collaboration: Being aligned with current sustainable supply chain literature (Carter and Easton, 2011; Sarkis, 2011; 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 (Parrno-Marchante et al., 2014). Supporetive governance and policies play an important role in creating an integrated approach, such as CE, to design, plan, support and coordinate for innovation and adaptation measures to environmental and social sustainability issues (Pan et al., 2018). Individual customer demands, in addition, drive companies and their supply chains to initially use Industry 4.0 to analyze customer specification in the process of production. By using smart machinery and devices, it can facilitate efficient transformation of customer requirements into production and operations (Fatorachian and Kazemi, 2018).

4.2 Barriers

Even though attentions have been raised in CE and industry 4.0 for sustainable supply chain operations, substantial barriers in implementation need to be highlighted to avoid misconduct. This research reveals that the main barriers in this regard can be decomposed as the complexity of dynamic system, lack of standards and legitimacy and data security, knowledge and technical incompetency, and high cost.

The complexity of dynamic system: The systemic perspective, on the one hand drives an integrated view to sustainability practice as discussed, 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 have quick response to changes, which leads 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. 2015). However, many supply chain actors, such as small and medium-sized enterprises (SMEs) or new supply chain contactors might find it challenge to invest in advanced technologic and information system for fulfilling the requirement of transparency and integration. Data overflow is another barrier in the complexity of dynamic system (Sjodin et al., 2018). The design and operation in the engineering system require specific methodologies to capture and solve the structural and behavioural challenges (Kuznetsova, Zio and Farel, 2016). However, uncertainty and risks will increase when innovative technology and the information system create massive opportunities, in the meantime, it can create frustration with the increase of number of complexity of choice (Sjodin et al., 2018). Instead of losing focus, companies might need to strategically decide their core competencies with consideration of the complex and dynamic nature rather than driven by the overwhelming data system.

Lack of standards and legitimacy and data security: Due to the complexity of the dynamic system, it is lack of standards and legislation for a common acceptance for CE and remanufactured products (Yang et al. 2018). It creates the most prevalent barrier to earn consumer trust in remanufactured products and restricts on international trading in certain countries. Another significant barrier for smart factories and Internet of things is inherent with vulnerability to interference and cyber-attack, challenging the safeguards and security procedures for sustainability supply chain operations (Fatorachian and Kazemi, 2018).

Knowledge and technical incompetency: Knowledge and skill incompetency is another barrier. Due to the rapid changes during the last two decades, it is still missing professional knowledge and necessary skills among the workforce for sustainability practices (Liboni et al. 2018; Sjodin et al., 2018). As a result, many limitations may encounter in life cycle design awareness and implementation, information sharing for design specifications and the reuse, repair and history of the returned products (Yang et al., 2018), and employment retaining for employees with innovative capabilities.

High cost: This study shares the insight that using advanced technology and building the integration system is costly. The costs of data collected and recorded in the technologic system, such as RFID, discarding the generalization of application in leveraging traceability in sustainable supply chain operation (Parreno-Marchante, 2013). With the maturity of technology development, the cost could be decreased in tendency; however, proactive firms willing to sustain their market leading positions need to pay the price at the current stage.

5. Integrating CE and Industry 4.0 for SSCM

5.1 CE in operations and SCM

Observations in this study show that the 3Rs – recycling, reusing and remanufacturing and the loop of supply chain are the key dimensions in the studies of CE in operations and SCM (Table 4).

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3Rs - recycle, reuse and remanufacture: 3Rs is regarded as the strategies for sustainable industrial practices with interconnected supply networks (Tseng et al., 2018). Reuse is ‘a generic term covering all operations where a return product is put back into service, essentially in the same form, with or without repair or remediation’ (Tolio et al., 2017, p.586). Recycle is to recycle product after its use for cost-effectiveness and environmental impact reduction (Peng et al., 2018; Tsai and Lai, 2018). Remanufacturing requests to return the used products to its original performance with a target that is at least equivalent that of the new product to fulfil a similar function to the original part (Tolio et al., 2017). The 3Rs contribute to resource efficiency, operational performance and waste management to preserve and enhance the use of natural capital and resources (Nobre and Tavares, 2017).

Taking a systemic view as discussed above, resent scholars provoke to extend 3Rs to

6Rs and include redesign (Moreno et al., 2018), regenerating, and repair into consideration (Jabbour et al., 2018). The extension of 6Rs emphasis a product's lifespan in a continuous and hierarchical strategy, which however, requires a highly integrated system and rarely implements in a real-world situation (Kim, Chang, and Park, 2017). Transparency and efficient communication are needed in the system to manufacture, transport, use, maintain and dissemble the end used products to be reuse, refurbish, remanufacture or recycle throughout their lifecycle (Iacovidou, Purnell and Lim, 2018).

Loop of supply chain – closed loop and opened loop supply chain: The loop of supply chain is not only included the forward supply chains, but also disposal and backward supply chains. It is closely related to the 3Rs in a hierarchy among the reverse logistics activities and that production should be redesigned with the purpose of enhancing lifecycle to improve the reuse, remanufacturing, recycling in product life extension (Bressanelli et al., 2018). Closing the loop requires corporate decision making across different industries in a multiple supply network (Tseng et al., 2017) in a 'industrial ecosystem' (Tolio et al., 2017, p.587). The activity in the closed loop supply chain takes into consideration of material selection, distribution planning, inventory and production control, and recycle and reuse issues (Kuo and Smith, 2018). It integrates the reverse process of collection, inspection, recycling and redistribution (Kim, Chang, and Park, 2017) in order to transform waste into valuable materials and assets (Moreno et al., 2018).

Different with closed loop supply chain, the opened loop supply chain involves degradation in the 'inherent material properties' and recycles material different from those of the virgin material (Tolio et al., 2017, p.587). For example, turning food waste into biofuel. Meanwhile, opened loop supply chain shares the similarity with closed loop supply chain to support effective reverse logistics system for material loops and efficient use of components (Lewandowski, 2016). The aim of loop of supply chain in CE to maximize the recovery of assets and turn the recycled materials into additional value (Lewandowski, 2016).

5.2 Industry 4.0 in operations and SCM

The Industry 4.0 has generated immense opportunities for unlocking the potential for CE and transform operations and SCM into a higher level of connectivity and efficiency (Yang et al., 2018). This study has revealed the following key dimensions influence on operations and SCM practices: Internet of things, cloud computing and big data analytics, smart factories, and automation (Table 5).

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Internet of things: The Internet of things (IoT), as one of the new technologies, has become a fashion making crucial impacts on modern industry. The term refers to the ‘interconnectivity between things, such as electronic devices, smartphones, machines, modes of transportation, and the internet, through unique identification codes which allow these things to communicate with one another to achieve common aims’ (Jabbour et al., 2018, p.277). The IoT establishes a large scale of sensor networks through information devices - such as the Radio-frequency identification (RFID) and wireless communication technology to integrate and collect data and share ability (Fang et al., 2015).

The world is of pervasive connectivity to improve production process and delivery via IoT. The IoT monitor collaborative processes by tracking and tracing on real time data for all collaborative network organization (Shamsuzzoha et al., 2016). Meanwhile, the IoT enables the operation meachines to have self-monitoring capabilities and communicate for real-time performance on production lines (Fatorachian and Kazemi, 2018). The implication of real-time checking and monitoring enables network organization to better diagnose and thus control operations process to deal with products, resources, persons and the system. The IoTs are believed as the key drivers for maximizing profits for operations and SCM (Rehman et al., 2016).

Cloud computing and big data analytics: The research finds that nowadays, cloud computing and big data analytics are the implementation mostly emphasized in the Industry 4.0. Could computing is the prevision of ‘computational, networking, and storage resources’ to lubricate the operational and financial tension in large-scale computing system; while big data is defined as the set of ‘structured, unstructured and semi-structured data accumulated from heterogeneous data source’ (Rehman et al., 2016, p.918). These systems enable high-storage capacity and remote communication of products and processes with high-speed data transformation (Fatorachian and Kazemi, 2018; Rehman et al., 2016). Based on cloud computing and big data analytics, accuracy, high speed performance and personalized units service can be delivered to customers through intelligent diagnosis and maintenance service, product operation optimization service and equipment manufacturing intelligent service (Zhang et al., 2017). Under the systems, managers can reduce the total operations and service cost while reducing risks in operations and SCM (Kuo and Smith, 2018).

However, the implementation of the cloud computing systems and big data analytics could be challenged in supply networks. The required capabilities are comprehensive while not transferable as a firm’s resources (El-Kassar and Singh, 2017). Companies in the end tiers of supply chains could face difficulties in acquisition, access, analytics and application of the information and resources in the systems. Besides, it also relates to the degree that how well stakeholders understand and accept the importance of such technologies and systems (Fatorachian and Kazemi, 2018). In this regard, we believe that the transformation of cloud systems and big data analytics to a broad range of operational implication is promising while evolving.

Smart factories: Smart factories are crucial at the core of Industry 4.0 to emphasize on intellectualized manufacturing system and process in a distributing network (Liu et al., 2016). Drawing on the uncertainty generated by the returned products, a high degree of flexibility is required in remanufacturing operations to react quickly to incorporate diverse product reconditioning requirements. Smart factories enable such high flexibility in small batch size production and address the complexity in the remanufacturing operations (Yang et al., 2018; Kuo and Smith, 2018). Compared with traditional manufacturing strategy, smart factories increase resource efficiency by using the pull principle where semi-finished materials are ordered on demand from their suppliers (Liboni, Liboni, and Cezarino, 2018). It is expected that the future factories will not only automatically connect and exchange manufacturing information and resources, but also the factories will smartly predict the current status of machines for the functions of product design, engineering and production control (Tsai and Lai, 2018). It can then yield potential benefits, such as increase process efficiency, increase product quality and sustainability, and decrease costs (Sjodin et al., 2018).

Automation: The development of Industry 4.0 reveals the implication of artificial intelligence and automation as a new wave of innovation in manufacturing and operations (Sjodin et al., 2018). The optimize actions in operations management are focused on increasing the efficiency and performance of a product and eliminating waste in the production and transportation processes, which can be leveraged by big data analytics, remote sensing and automation (Lewandowski, 2016). For example, artificial intelligence has been used in renewable and electrical energy to achieve better efficiency and forecast energy consumption (Kuo and Smith, 2018). Automation has been applied in smart factories (Sjodin et al., 2018), big data analytics (Jose and Ramakrishna, 2017), and 3Rs (Tullio et al., 2017). The core feature of Industry 4.0 is to connect machines, orders, people using IoT and autonomous systems (Jabbour et al., 2018).

5.3 Findings on SSCM

With response to 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).

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5.3.1 Economic sustainability

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 (Jabbour et al.,2018). Meanwhile, the 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 better communication system and information flow (Despeisse et al., 2017). Firms are able to make radical improvement of material efficiency by eliminating material wastes in all processes with transparent flow (Despeisse et al., 2017).

Industry 4.0 based supply chains meet the need for building a comprehensive tracking and tracing system for improving operational efficiency in contemporary supply chain (Verdouw et al., 2018). It is of significance while challenges for international logistics and supply chains to address the sophisticate 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 get all the information of 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).

Operational costs: The creation of operations efficiency in such tracking and tracing system can reduce operational costs (Lacovidou, Purnell and Lim, 2017; Nobre and Tavares, 2017). With the application of Industry 4.0 and CE, the service of core produce and competencies can be improved for economic growth (Lewandowski, 2016; Zhang, 2017) with lower production costs (Nobre and Tavares, 2017), such as transportation cost (Mladineo et al., 2018), project costs (Iacovidou, Purnell and Lim, 2017), and data utilization cost (Rehman et al., 2016). For example, by tracking and tracing perishable product, firms can improve the management of food waste and recalls under better control of products and processes; meanwhile, the automate scanning can reduce labour and enhance stock control for reducing operational costs (Parreno-Marchante et al., 2013).

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

5.3.2 Environmental sustainability

Decrease environmental impact: When enterprises move towards sustainability, CE and Industry 4.0 increase the process of developing new products, processes and services while decrease environmental impacts, which can be summarized as the factors of *eco-innovation* and *pollution and greenhouse gas emission reduction*.

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, p.208). The 3Rs and loop of supply chain 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, provoked 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 Singh, 2017).

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 chemicals pollutions (Franco, 2017). Greenhouse gas emission, such as CO_2 emissions seriously worsen the global climate change (Tsai and Lai, 2018; Yang et al., 2018). Through proper reuse, repairing, and maintenance the end of used products in CE, it is efficient to reduce carbon emission, toxicity and optimism the use of virgin resources (Iacovidou, Purnell and Lim, 2017). In addition, the enhanced process in Industry 4.0 enables the reduction of pollution and greenhouse gas emission in a tracking system with sufficient data supports (Liboni, Liboni, and Cezarino, 2018). Supported by the Industry 4.0, the reduction of environmental impacts can be improved by product design, material selection and efficient recycling processes (Jose and Ramakrishna, 2018).

Waste reduction: Integrating CE and Industry 4.0, companies enhance their capabilities in emphasizing on waste reduction, which is strongly related to reuse, recycle and remanufacture end-of-life product to reduce waste in SCM. Manufacturers take responsibilities 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 roborts and machine learning to revolutionize waste sorting and product disassembly systems (Liboni, Liboni, and Cezarino, 2018) to reduce waste. Through 3Rs, highest value of a physical properties of a product can be kept and avoid emissions generation (Moreno et al., 2018; Fang et al., 2015). 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).

Resource consumption reduction: It seems that integrating CE and Industry 4.0 is one of the alternative to resolve resource scarcity for reducing resource consumption in sustainable development. The primary focus of 3Rs, or 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, p.834). Meanwhile, Industry

4.0 such as data sharing and big data analytics enables knowledge driven for value creation (Rehman et al., 2016). The supporting technologies and information act as the fundamental role for sustainability operations and SCM.

5.3.3 Social sustainability

Observation in this study reveals that social sustainability in operations and SCM is yet in the infant stage in the integration of CE and Industry 4.0. ***Safety*** is a positive side of integrating CE, particularly Industry 4.0 in sustainability practice. Automation in processes may reduce potential error, such as industrial accidents for human safety (Liboni, Liboni, Cezarino, 2018; Sjodin et al., 2018). At social level, it increases the confidence over 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 of reducing repetitive and fatiguing work activities in Industry 4.0 (Sjodin et al., 2018). ***Job opportunity*** seems to be the debatable 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 for job security and redundancy (Fatorachian and Kazemi, 2018; Parreno-Marchante et al., 2014). Yet, it is in revolution for implementing advanced technologies in industrial, where not only economic and environmental sustainability, but social and human responsibilities should be took into concerns in long term.

6. Discussion

6.1 Integration of CE and industry 4.0

The principle of sustainability and SSCM heavily dependent on the availability of resources (Baykasoglu 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.

Developed the current literature (e.g. Lewandowski, 2016), this study found that there is a great connectivity between Industry 4.0 and CE, in particular, the implication of innovative technologies and information system in Industry 4.0 enables CE application in SSCM (Figure 2). The main contribution of CE is to make the maximum utility and value of products and resources (Lewandowski, 2016; Tolio et al., 2017). However, coherent with the benefits, the challenges of applying CE in SCM is due to the complexity of the dynamic system where imposts the difficulty of using advanced technologies and big data information (Verdouw et al., 2015; Sjodin et al., 2018). In this regard, 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 loop of supply chain (Tseng et al., 2018). Meanwhile, the use of IoT and big data analytics plays a significant role for enhancing company's knowledge competency for further analysis and understand the intellectualization of the existing system, helping to support decision making and better implement CE (Zhang et al., 2017). Drawing on this finding, we propose that:

Proposition 1: The implications of Industry 4.0 and CE are connected; in particular, Industry 4.0 tackle the barriers of understanding the complex mechanism in the dynamic system and enhancing knowledge and technological competency for adopting CE.

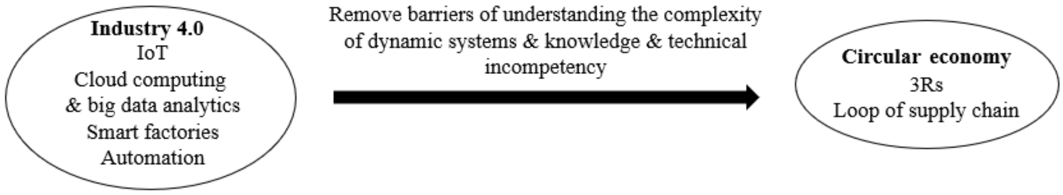

Figure 2: Connection of Industry 4.0 and CE

6.2 The roadmap towards SSCM: A dynamic capability view

Observations in this study show an interlink between Industry 4.0, CE and SSCM, mainly focus on economic and environmental sustainability discussed above. Yet, the understanding of the complexity in the dynamic system is in its infant stage. In particular, when Industry 4.0, CE and sustainability require intensive integration and collaboration in supply network (Carter and Rogers 2008; Morali and Searcy 2013), the dynamic capability view is adopted in this study to provoke a dynamic change and evolvement for SSCM.

Teece et al. (1997) has generated a growing flow of research of dynamic capabilities to explain competitive advantage and performance on high velocity and dynamically change of markets. Definition of dynamic capabilities is riddled with inconsistencies. According to Teece et al. (1997, p.516), dynamic capabilities is '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 highlights the underpinning theories, including nature, role, context, creation, outcome and heterogeneity. The natural 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 recourses routines of firms. More recently, Helfat (2007, p.1) define 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 specific purposes of integrating and reconfiguration resources and sustaining competitive advantage.

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 proposed a framework for mapping SSCM with integration of Industry 4.0 and CE from a system dynamic view (Figure 3).

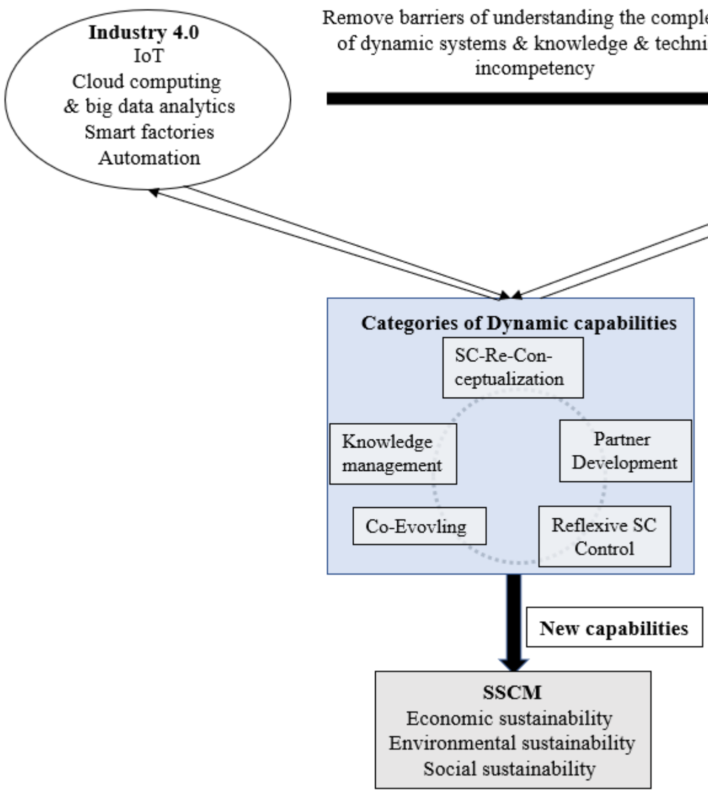

Figure 3: The roadmap to SSCM

Being aligned with the current study from Beske (2012), the framework includes five categories of dynamic capabilities to take into concerns of supply chain Re-conceptualisation, partner development, knowledge management, co-evovling and reflexive supply chain control.

Supply chain Re-Conceptualization: New partners could be local communities or third party, not necessary being part of the original supply chain (Pagell and Wu, 2009), which can provide specific supports and contacts. Addressed as one of the key driver, different stakeholders, such as government policy-makers, practitioners, educators and non-profit organization could enhance knowledge sharing and integrate sustainability into policies and management practices (Pan et al., 2018). The implication of CE enforces supply chain Re-Conceptualization to include new partners for resource efficiency and supply chain performance. CE is increasing important worldwide, for example the G7 Summit Declaration of June 2015 has launched the 'Alliance on Resource Efficiency' to promote CE. In turn, supply chain Re-Conceptualization foster knowledge sharing and resources integration for Industry 4.0 and CE. When discussing on the loop of supply chain, it involves corporate decision makers among multiple supply networks across different industries (Tseng et al., 2018). Therefore, we propose that:

Partner development: This category is a necessary capability for developing the partners in order to accomplish supply chain tasks and actives, following a sustainability strategy as a whole (Seuring and Muller, 2008). There is an interlink among partner development, Industry 4.0 and CE. It is in a pervasive connectivity among supply chain partner, which enables constant feedback from physical devices and Industry 4.0 to improve production process and delivery in SCM (Fatorachian and Kazemi, 2018). Likewise, optimal partner development is essential for CE, such as remanufacturing in the closed-loop supply chain (mladineo et al., 2018).

Knowledge management: It is the category enables the understanding of knowledge possessed by the supply chain partners and stakeholders (Defee and Fugate, 2010). It was discussed above how Industry 4.0 can improve knowledge sharing and understanding for CE implementation. We argue that it is in a dynamic process that the more knowledge and skills companies incorporate, the more competencies that they can implement Industry 4.0 and CE, supporting by the study from Zhang et al. (2017).

Co-evovling: This category is related to the managers reconnected webs of collaboration in order to generate new resource and synergies to enhance the overall supply chain performance (Pagell and Wu, 2009). As mentioned in the above text that suppliers might find it difficult to invest and share the same vision for Industry 4.0 and CE. Therefore, it is of importance to draw on the co-evolving capabilities to integrate network resources and competencies in this regard.

Reflexive supply chain control: This category emphasizes on constantly check and evaluate business practices against requirements in SCM (Beske et al., 2014). The cloud computing and big data analytics in Industry 4.0 increase the dynamic capabilities to monitor the effective and timely implement of CE in practice (Zhang et al., 2017; Shamsuzzoha et al. 2016).

Drawing on the discussion above, we propose that:

Proposition 2: Industry 4.0 and CE enhance dynamic capabilities in SCM; in turn, dynamic capabilities foster supply chain Re-Conceptualization, partner development, knowledge management, co-evolving, and reflexive supply chain control for Industry 4.0 and CE.

This study revealed a lack of research and knowledge to integrate Industry 4.0 and CE in SSCM. The current literature has focused on economic and environmental sustainability, such as operational efficiency (Jabbour et al.,2018; Despeisse et al., 2017), environmental impact (Kuznetsova, Zio and Farel, 2016; Kuo and Smith, 2018) and waste reduction (Liboni, Liboni, and Cezarino, 2018), however, the underlying mechanism that how companies gain competitive advantage from the dynamic changes of complexity is missing. Besides, the research on social sustainability is rare, and the influence on job opportunities is unclear (Fatorachian and Kazemi, 2018). The dynamic capabilities view offer a theoretical lens to understand the complex and evolving system how companies and their supply chain improve SSCM implementation overtime (Beske et al., 2014). Therefore, we proposed that:

Proposition 3: Dynamic capabilities integrated in Industry 4.0 and CE can create new capabilities for SSCM implementation.

7. Conclusions

A recent report of the United Nations Industrial Development Organization indicates Industry 4.0 as one of the accelerators of 'sustainable energy'. Therefore, integration of Industry 4.0 and sustainability can provide more effective means to control the production system as compared with that of the traditional centralised system. This study has found the substantial interlinks between Industry 4.0 and CE, aiming to remove barriers of understanding the complexity of dynamic systems and incorporate with knowledge and technical incompetency for SSCM. This research also proposes a conceptual framework where demonstrate 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 contributions

There is a need of research to understand Industry 4.0 driven and CE context for sustainability operations. This study makes the theoretical contributions as threefold: firstly, this study systematical reviews the drivers and barriers to integrate CE and Industry 4.0 in SSCM. The discussions have uncovered a holistic view of systemic changes together with operational and relational factors for further researches on their implementation. Second, main categories in CE and Industry 4.0 are revealed with discussion on research gaps for further research development. Finally, by taking a dynamic capability view, this research provokes a roadmap to SSCM where empirical research can be carried on to discuss on the implication of the framework.

7.2 Industrial contributions

This paper has significant industrial contributions. The review of specific categories in CE, Industry 4.0 and SSCM help practitioners to invest their business and operations to gain competitive advantages. For example, in the UK, the Food and Drink Federation has identified Industry 4.0 as one of the '*pre-competitive areas*' in the food industry

(Mondelez International, 2017). CE is viewed as the condition for sustainability (Geissdoerfer et al., 2017) which is embedded in the Courtauld Commitment 2025 (WRAP, 2018). Courtauld 2025 aims to improve sustainability aspect in the UK's food and drink sector through enhanced resource efficiency and more waste reduction. Manufacturers participating in both Courtauld 2025 and Industry 4.0 agendas, such as Cadbury, Mars Nestlé, Heinz, Premier Foods and Kerry Noon, and grocery retailers, such as Asda and Morrisons, are striving to achieve waste reduction, improved packaging and carbon footprint reduction. This paper would provide a better understanding to industrial managers on how to achieve sustainability in supply chain operations through CE and Industry 4.0.

7.3 Limitation and future research opportunities (food supply chain)

This paper has its own limitations. The research findings are based on the current literature; therefore, it could be contested in terms of discussion for the implementation of results. Theoretical framework testing and development can be addressed as future research opportunities, for example, to discuss on to what extent the research findings could be applied in food industry in the UK and other emerging economics.

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Tables:

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

Table 2 Criteria for inclusion or exclusion papers

Inclusion 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
The selected articles contain at least one keyword in their title or abstract	Abstract or title focusing on the circular economy and industry 4.0 on the context of sustainable supply chain management was selected
Judge relevance by fully reading all remaining abstract, introduction and conclusion	The remaining abstract, introduction and conclusion focusing on the circular economy and Industry 4.0 on the context of sustainable supply chain management was selected
Judge relevance by fully reading all remaining articles	Articles focusing on the circular economy and Industry 4.0 on the context of sustainable supply chain management was selected

Source: Authors

Table 3 Criteria for conducting analysis based on the general information of studies

Type of analysis	Aim
Date of publication	Verification of timeliness of how industry 4.0 and circular economy has been evolved over time in the context of operations and SCM
Location	Analyse geographical location of authors to investigate the development of industry 4.0 and circular economy in the context of operations and SCM in different countries
Methodology used	To investigate which methodology has been used such as theoretical and conceptual papers, case studies/interviews, surveys, modelling papers and literature review papers (Winter and Knemeyer. 2013)
Theory adopted	To investigate which theory has been adopted in different papers

Source: Authors

Table 4. Findings of circular economy in operations and SCM

Dimensions	Core concept	Key papers	No. of papers
3Rs			**20**
Recycle	‘a generic term covering all operations where a return product is put back into service, essentially in the same form, with or without repair or remediation’ (Tolio et al., 2017, p.586)	Teseng et al., 2018; Kim, Chang, and Park, 2017; Kuo and Smith, 2018	8
Reuse	Recycle is to recycle product after its use for cost-effectiveness and environmental impact reduction (Peng et al., 2018)	Iacovidou, Purnell and Lim, 2017; Lewandowski, 2016; Verdouw et al., 2015	6
Remanufacture	Remanufacturing requests to return the used products to its original performance with a target that is at least equivalent that of the new product to fulfil a similar function to the original part (Tolio et al., 2017)	Kusiak, 2018; Tullio et al., 2017; Yang et al., 2018	7
Loop of supply chain			**14**
Closed loop supply chain	‘In closedloop recycling, the inherent properties of the recycled material are not considerably different from those of the virgin material, thus substitution is possible’ (Tolio et al., 2017, p.587)	Tolio et al., 2017; Tseng et al., 2017; Kuo and Smith, 2018; Kim, Chang, and Park, 2017	13
Opened loop supply chain	‘In open-loop recycling, the inherent properties of the recycled material differ from those of the virgin material in a way that it is only usable for other product applications, substituting other materials’ (Tolio et al., 2017, p.587).	Lewandowski, 2016; Tolio et al., 2017	4

Source: Authors

Table 5: Findings of Industry 4.0 in operations and SCM

Dimensions	Core concept	Key authors	No. of papers
IoT	It refers to the 'interconnectivity between things, such as electronic devices, smartphones, machines, modes of transportation, and the internet, through unique identification codes which allow these things to communicate with one another to achieve common aims' (Jabbour et al., 2018, p.277).	Jabbour et al., 2018; Fang et al., 2015; Fatorachian and Kazemi, 2018	16
Cloud computing and big data analytics	'Cloud computing and big data analytics Computing power offered by high-tech computers has created a great platform for analysing big data generated from IoT' (Fatorachian and Kazemi, 2018 ,p.637).	Rehman et al., 2016; Fatorachian and Kazemi, 2018; Kuo and Smith, 2018	19
Smart factories	Smart factories increase resource efficiency by using the pull principle where semi-finished materials are ordered on demand from their suppliers (Liboni, Liboni, and Cezarino, 2018).	Liboni, Liboni, and Cezarino, 2018; Sjodin et al., 2018; Yang et al., 2018	13
Automation	The core feature of Industry 4.0 is to connect machines, orders, people using IoT and autonomous systems (Jabbour et al., 2018).	Tullio et al., 2017; Lewandowski, 2016; Sjodin et al., 2018	6

Source: Authors

Table 6: Findings of SSCM

Dimensions	Core concept	Key authors	No. of papers
Economic sustainability			**22**
Operational efficiency	Companies and their supply chains potentially increase operations efficiency in terms of increasing material flow, and enhancing the tracking and tracing system.	Jabbour et al.,2018; Despeisse et al., 2017; Verdouw et al., 2018	16
Operational costs	The creation of operations efficiency in such tracking and tracing system can reduce operational costs (Lacovidou, Purnell and Lim, 2017)	Lacovidou, Purnell and Lim, 2017; Nobre and Tavares, 2017;	7
Risk control	Integrating circular economy and Industry 4.0 can mitigate the system risks and errors.	Nobre and Tavares, 2017; Liboni et al., 2018	2
Environmental sustainability			**27**
Environmental impact	When enterprises move towards sustainability, circular economy and Industry 4.0 increase the process of developing new products, processes and services while decrease environmental impacts.	Kuznetsova, Zio and Farel, 2016; Kuo and Smith, 2018; Liboni, Liboni, and Cezarino, 2018	19
Waste reduction	Companies enhance their capabilities in emphasizing on waste reduction, which is strongly related to reuse, recycle and remanufacture end-of-life product to reduce waste in SCM.	Liboni, Liboni, and Cezarino, 2018; Kuo and Smith, 2018; Lewandowski, 2016	15
Resource consumption reduction:	It seems that integrating circular economy and Industry 4.0 is one of the alternative to resolve resource scarcity for reducing resource consumption in sustainable development.	Kuznetsova, Zio and Farel, 2016; Kuo and Smith, 2018; Rehman et al., 2016	12
Social sustainability			**11**
Safety	Integrating circular economy and Industry 4.0 can improve safety level for workforce and society.	Liboni, Liboni, Cezarino, 2018; Sjodin et al., 2018	4
job satisfaction	Reducing repetitive and fatiguing work activities in Industry 4.0 to	Sjodin et al., 2018	1

	improve job satisfaction (Sjodin et al., 2018)		
Job opportunity	Job opportunities can be created in the after-sales service market (Yang et al., 2018); however, automation could cause concerns for job security and redundancy (Fatorachian and Kazemi, 2018)	Fatorachian and Kazemi, 2018; Yang et al., 2018	4

Source: Authors