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Integrating product design and supply chain management for a circular economy

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ABSTRACT

Circular economy (CE) provides an alternative development model to the dominant take-make-dispose linear approach, and thus a new vision for solving sustainability challenges. Firms need to operationalise CE in their supply chain operations, starting from circular product design as the foundational step. The purpose of this paper is to investigate how to integrate product design and supply chain management (SCM) decisions for a CE transition. A thematic analysis was conducted on data collected from 15 semi-structured interviews in New Zealand. Four propositions were established based on the identified themes, namely, end-of-life thinking in product design, circular SCM, business model innovation, and sustainable organisational values. The study results provide a novel insight into the integration of product design and SCM for a CE transition. The operational framework developed provides guidance to product designers, managers, and researchers to advance the CE cause at the supply chain level.

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Circular Economy; Circular Product Design; Supply Chain Management; Business Model Innovation; Circular Supply Chain

1. Introduction

Over the past 50 years, there has never been a period of stabilisation or decline in the demand for resources (Oberle et al. 2019). Serious environmental problems have emerged with excessive resource extraction and consumption, such as pollution (in air, water, soil), resource scarcity and depletion, loss of biodiversity and ecosystems, and climate change (Murray, Skene, and Haynes 2017). A major cause of these sustainability problems is the dominant linear economic model (MacArthur 2013), in which resources and products move in a unidirectional flow as take-make-dispose.

Circular economy (CE) is an alternative to the traditional linear model and is regarded as the best option to combat the sustainability problems facing society in the modern era (Geisendorf and Pietrulla 2018; Gregson et al. 2015). CE is regenerative and restorative by design (MacArthur 2013) and is characterised by circular resource flows in the economy (Su et al. 2013). Specifically, through innovative product design and waste management, CE substantially increases the rate of reuse, remanufacturing, and recycling of technical materials and preserves natural capital by utilising biological materials indefinitely (Jabbour et al. 2018). Underpinned by a transition to renewable energy sources, CE builds economic, natural, and social capital based on three principles: design out waste and pollution, keep products and materials in use, and regenerate natural systems (Ellen MacArthur Foundation 2017).

It is clear that design innovation is essential for a transition to CE. Product design requires a fundamental rethinking to design out waste and pollution in the circular system. In the linear economy model, products are not designed with end-of-life options in mind and thus largely end up in landfills, with the embedded resources lost to the waste stream indefinitely. From the economic perspective, the products in the linear model are more likely to follow the design strategy of planned obsolescence in order to stimulate repeat consumption and production and thus profits (Bridgens et al. 2019). However, linear product design continuously creates wastes and increases the business risks under the threat of natural resources shortage (Eichner and Pethig 2001). In contrast, circular product design, i.e. product design in line with CE principles, enables the circularity of the consumed resources from the 'point of origin' through the use of disassembly and reassembly design, long-life products, and product-life extension amongst others (Bocken et al. 2016). Consequently, products designed according to CE principles are the solution rather than the problem for the ecosystem, in contrast to the linear economy. The products and their embedded resources in the circular system create economic opportunities (e.g. reduction in production and procurement costs), improve environmental performance through waste reduction and biological decomposition, and generate employment in both high and low skilled areas (Wijkman and Skånberg 2015).

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CE needs to be operationalised at the supply chain level to create a truly circular system. In modern business, firms operate and compete largely across the supply chains (Tate, Ellram, and Dooley 2012). The production and usage of materials are highly interdependent between supply chain partners. Supply chain collaboration is essential for improving environmental and financial performance (Liu and De Giovanni 2019). The development of a circular system of materials restoration and regeneration also relies on supply chain partners, for example, waste management organisations. The present supply chain management (SCM) concept is rooted in a linear model as represented by its name and its nature as a 'chain' (Jain, Jain, and Metri 2018). In the linear nature of SCM, the existing forward chain is efficient with regard to operational performance (e.g. cost and speed), while the addition of restoration and regeneration functions (e.g. reverse chains) disrupts such efficiency (Pagell and Wu 2009). Nonetheless, urgent sustainability challenges, particularly the increased risk of resource shortage, require a circular SCM in line with CE. A circular SCM is able to develop system-wide innovations from the acquisition of raw materials to end-of-life product and waste management, where all supply chain actors systematically restore technical materials and regenerate biological materials towards a zero-waste vision (Farooque, Zhang, Thürer, et al. 2019).

As an emerging concept that operationalises sustainability, CE has attracted growing interest among researchers (Farooque, Zhang, Thürer, et al. 2019; Geissdoerfer et al. 2017; Ghisellini, Cialani, and Ulgiati 2016). Scholars have studied the frameworks to guide CE adoption (MacArthur 2013) and the relationship between CE and sustainability (Geissdoerfer et al. 2017). With the legislation of CE at the national and regional levels (e.g. Germany, China, European Union), many studies have focussed on the top-down approach of CE adoption (Geng et al. 2012; Geng and Doberstein 2008). However, very few studies have explored firm-level CE implementation barriers (Farooque, Zhang, and Liu 2019; Mangla et al. 2018). Overall, firm-level CE research is still nascent. In particular, there has been limited research on the integration of product design and SCM for operationalising CE. Product design and SCM, as mentioned earlier, are both of fundamental importance in the implementation of CE, and they are related to each other. Nevertheless, to the best of our knowledge, their integration has not been investigated in the context of CE. To narrow this knowledge gap, this study addresses the following research question:

> How should product design and supply chain management be integrated for a transition to CE?

To answer this research question, this study developed an operational framework that incorporates circular product design and SCM based on data from 15 semi-structured interviews in New Zealand. Thematic analysis was used to code the interview data from experienced practitioners and researchers to explore the key components and their relationships in the CE operational system. The thematic analysis uncovered four themes: 'end-of-life thinking in product design', 'circular SCM', 'business model innovation', and 'sustainable organisational value'. At the strategy level, a transition to CE must start with a firm's commitment to sustainable organisational values and a CE vision. At the operations level, circular product design is the starting point of CE implementation, and it must incorporate end-of-life thinking to facilitate value recovery in end-of-life product and waste management. Circular SCM operationalises the restorative cycles of technical materials and the regenerative cycles of biological materials, closing the loops of resource flows. Business model innovation aligns economic incentives with environmental objectives in a circular production and consumption system to improve financial viability.

This research makes two significant contributions. First, based on qualitative empirical data, this study extends the literature of supply chain operations for CE from the perspective of product design. Product design with end-of-life thinking is an effective starting point for circular supply chain collaboration, providing a new dimension of circular SCM for a transition to CE. Second, this study provides an integrated framework centred upon circular product design and circular SCM to operationalise CE. The developed operational framework incorporates the interplays of critical factors and provides guidance to product designers, managers, and researchers to advance the CE cause at the supply chain level.

The remainder of this paper is organised as follows. Section 2 reviews the relevant literature. Section 3 explains the data collection procedure and the thematic analysis method. Section 4 presents the findings. Section 5 advances several general propositions based on the research findings, develops the operational framework, and discusses managerial implications. Section 6 concludes the study.

2. Literature review

2.1. Circular economy

The CE concept is an alternative to the dominant linear take-make-dispose industrial model. CE aims to decouple economic growth from the consumption of finite resources and continuous waste generation (Geissdoerfer et al. 2017). The CE model has a regenerative and restorative nature and is underpinned with the use of renewable energy sources (MacArthur 2013). CE promotes continuous resource cycles that preserve and enhance natural capital while optimising resource yields (Moreno et al. 2016). The cyclical flow of materials is also known as the cradle-to-cradle approach, allowing for resources to be used to their maximum potential. The essence of CE is to improve resource productivity by ensuring that products and resources are used as long as possible (Yuan, Bi, and Moriguichi 2008).

Over recent decades, there has been increasing concern over the threat of resource depletion (Georgescu-Roegen 1986; Ghisellini, Cialani, and Ulgiati 2016; Miller 1977). Prior to CE, various studies explored solutions to sustainability challenges, including the Performance Economy (Stahel 2010), the Blue Economy (Pauli 2010), Biomimicry (Benyus 1997), and Natural Capitalism (Hawken, Lovins, and Lovins 2013). However, these concepts follow a cradle-to-grave approach, where products and resources end up in landfills, albeit at a delayed pace (Jain, Jain, and Metri 2018). CE is a synthesis of different schools of thought but most closely emulates the work of McDonough (2002), where a cradle-to-cradle approach is conceptualised. Following this approach, CE has been designed with a holistic, economic, industrial, and social framework that aims to ultimately eliminate all waste from product lifecycles while being powered by renewable energies with a focus on natural system design.

CE is underpinned by biological and technical cycles (MacArthur, Zumwinkel, and Stuchtey 2015). The biological cycle focuses on regeneration in ecosystems by using renewable materials and reducing excessive extraction of natural resources. The products and resources at the end of the lifecycle should be nutrients that are returned to the ecosystem through composting, anaerobic digestion, or cascading processes (McDonough 2002), which in turn derives renewable resources and new products. The technical cycle emphasises restoration from wastes and by-products through reuse, repair, remanufacture, and recycling. Hence, what is regarded as waste is converted to valuable resources in other production systems (Jabbour et al. 2018). These two cycles complement each other and produce the circular flow of materials and resources.

CE implementation has been accelerated by the Ellen MacArthur Foundation, which spearheaded the movement through education of the public and by developing frameworks for businesses and governments to uptake circular processes (Ellen MacArthur Foundation 2013). The European Union made significant progress towards CE with the 'EU Action Plan for the Circular Economy'. Japan, the US, and China also pioneered their movements towards CE principles with legislative and regulatory changes, and eco-industrial parks. CE practices have been largely implemented with a top-down approach, changing the policies, technology development, and society (Geng and Doberstein 2008).

The macro- and meso-level implementations of CE shift policies and raise public awareness concerning the improvement of circularity in the economic system. While business firms are increasingly pressured by such top-down implementations of CE worldwide, they should proactively adopt the circular system in operations due to the potential synergy of economic, environmental, and social performance through CE (Genovese et al. 2017). At the firm level, product design with circular thinking is important for improving the regeneration of resources and thus achieving the biological cycle. From the perspective of the technical cycle, the circular supply chain operations in, for example, waste management, is the ultimate solution to reach true restoration. Product design and SCM and their conceptual relationships to CE are reviewed in the next subsections.

2.2. Supply chain management for a circular economy

The unidirectional flow of resources from upstream to downstream is a typical attribute in the present supply chains. Traditional SCM largely focuses on developing strategies (e.g. lean) based on this linear relationship to improve operational efficiency (Pagell and Wu 2009), and thus is unlikely to accommodate sustainability issues (Pagell and Shevchenko 2014).

There has been increasing SCM research that incorporates sustainability concepts. Srivastava (2007) presented a state-of-the-art literature review on the development of the 'green supply chain management' concept, introducing the concepts of green design, green manufacturing, reverse logistics, and waste management. Seuring and Müller (2008) developed a conceptual framework of 'sustainable supply chain management', demonstrating supplier management for risks and performance and supply chain management for sustainable products as two strategies that incorporate both environmental and social impacts in SCM. Souza (2013) reviewed 'closed-loop supply chains', where there is a reverse flow of used products back to manufacturers in addition to typical forward flows. These previous studies substantially advanced the development of SCM from the sustainability perspective.

Circular SCM was developed from past research to conceptualise a circular system at the supply chain level. Circular SCM is based on the cradle-to-cradle approach to integrating supply chain operations, and especially on the circulation of resources flow and waste management (Weetman 2016). This study follows Farooque, Zhang, Thürer, et al. (2019) to define circular SCM as 'the integration of circular thinking into the management of the supply chain and its surrounding industrial and natural ecosystems. It systematically restores technical materials and regenerates biological materials towards a zero-waste vision through system-wide innovation in business models and supply chain functions' (p. 884). Circular SCM drastically reduces the demand for virgin resource extraction by circulating biological materials in regenerative cycles and technical materials in restorative cycles, with a vision of zero-waste.

A major development of circular SCM that builds on other concepts is to include both closed- and open-loop supply chain design (Farooque, Zhang, Thürer, et al. 2019). One of the critical components in circular SCM is reverse logistics activities that create a backward flow of resources and produce the related information to achieve circularity in supply chains (Larsen et al. 2017). This circularity can be a closed-loop, where firms working at the same supply chains collaborate to recover the value of wastes and biological nutrients (Guide and Van Wassenhove 2009). Circular SCM should also support open-loop supply chains, where waste value can be recovered by supply chain coordination and collaboration in the same industry sector (i.e. open-loop same sector) or from different sectors (i.e. open-loop the other sector). With both closed- and open-loop circular SCM, the wastes are continuously absorbed as inputs for the same and different supply chains (Genovese et al. 2017).

2.3. Product design for a circular economy

Product design is a powerful technique dealing with sustainability challenges (Papanek and Lazarus 2005). The sustainability impact of products at the end of the lifecycle heavily depends on their design and the conception phase (Kobayashi 2006). After the design stage, it is difficult to make changes to product concepts, resource allocation, and infrastructure (Bocken et al. 2016). Thus, it is important to integrate CE principles into product design. 'Circular product design' can significantly reduce the barriers to waste management and improve innovative and flexible use of resources, which increases social acceptance and facilitates the circular system both in terms of production and consumption.

Eco-design and Design for Sustainability (DfS) are two important sustainability concepts that address environmental concerns through product design. Both concepts provide the theoretical foundation to advance to circular product design.

2.3.1. Eco-design

Eco-design aims at mitigating environmental challenges with sustainable design solutions applied to products, services, or systems (Karlsson and Luttropp 2006) . The true environmental impact of a product or process must be measured from the design and conception phase, right through to the end of life (Kobayashi 2006). Eco-design utilises a four-level model to address environmental concerns: product improvement, product redesign, function innovation, and system innovation (Brezet 2000). Product improvement and product redesign focus on the nature of products, either redesigning products or improving products to be environmentally sustainable. At the strategic level, function innovation dematerialises services from products, and system innovation considers that new products and services arise from innovation (Kobayashi 2006).

In addition to addressing environmental concerns, eco-design also accommodates economic factors throughout the lifecycle (Charter and Tischner 2017). The systematic design of environmental concepts into products and processes mitigates supply chain sustainability risks, creates competitive advantages, reduces production costs, provides new sales channels, and strengthens regulatory relationships (Knight and Jenkins 2009). Also, eco-design uses inspiration from a wider field of positive examples of smart production methods, effective system solutions, and attractive designs (Karlsson and Luttropp 2006), which continuously improve the ergonomic, economic, aesthetic, and environmental values of the products and services.

2.3.2. Design for sustainability

DfS is a design strategy developed in the 1990s as an evolution of the eco-design concept (Spangenberg, Fuad-Luke, and Blincoe 2010). DfS places higher importance on social, economic, and ethical dimensions than eco-design while maintaining and enhancing the environmental aspects of design. DfS aims to apply elements of lifecycle thinking to the design stage and should be used as a tool for designers to express their designs in a sustainable manner. Spangenberg, Fuad-Luke, and Blincoe (2010) point out that DfS does not place limitations on design but rather asks designers to solve their problems by providing better alternatives. This concept builds on the methodology of sustainable consumption and sustainable production but remains on the boundaries of design education and practice (Bhamra and Lofthouse 2016). DfS is considered a design strategy for a closed loop so that resources are utilised continuously within a system.

2.3.3. Circular product design

The concept of circular product design is derived from DfS and eco-design (Moreno et al. 2016). However, circular product design changes the cradle-to-grave approach embedded in these preceding strategies to the cradle-to-cradle method, placing a high emphasis on product design to continuously improve and ultimately achieve the indefinite circulation of resources (Andrews 2015). Circular product design requires system thinking on products. Both consumers' perception and consumption patterns can be influenced by such design, and thus, industry and society can move away from careless resources depletion and adopt the circular system (Moreno et al. 2016). Circular product design represents an early integration of circular thinking into the product lifecycle, providing a high level of flexibility to incorporate sustainability management and infrastructure at the production and consumption level (Bocken et al. 2016).

Circular product design strategies mainly focus on slowing and closing resources loops (Bocken et al. 2016). The resources loops can be slowed by designing long-life products and product-life extension. The increase in the emotional durability (e.g. attachment and trust) of products in addition to physical durability is more likely to create long-life products. Product life can be extended by improving the upgradability and adaptability of the products at the design level. A closed resources loop can be approached by designing for technical and biological cycles, and disassembly and reassembly. In designing for a technical cycle, designers should aim at facilitating recycle, reuse, and remanufacturing of the product wastes. In designing for a biological cycle, products should be designed with biodegradability to create biological nutrients for a new natural system. Finally, products design should simplify disassembly and reassembly, which supports the functions of technical and biological cycles.

The CE system cannot operate without products that support the circular strategy, preferably by intention and design (Den Hollander, Bakker, and Hultink 2017). Circular product design enables a high degree of product flexibility and adaptability to the circular system at the later production and consumption stages. Therefore, circular product design is a foundational step in CE adoption.

To summarise the literature review, there has been increasing interest from both academics and practitioners in the transition to CE. Some recent works have studied the concepts of circular SCM and circular product design separately. However, extant research has not investigated how businesses can integrate circular SCM and circular product design into their daily operations. Using qualitative data collected from experienced professionals, this study seeks to fill the knowledge gap by developing an operational framework that guides firms' adoption of CE integrated with product design and SCM.

3. Methodology

Semi-structured interviews and thematic analysis were used in this study. Supply chain research on CE is nascent, and the related theories are evolving (Murray, Skene, and Haynes 2017). A qualitative approach is more likely to support the exploration of new concepts and deeper insights into related areas. Thematic analysis focuses on identifying patterns and themes within data and looking for implicit and explicit meaning in the data (Aronson 1995). A theme is a conceptualised idea that captures shared meaning around an organised core concept (Braun and Clarke 2006). Thematic analysis is an inductive reasoning approach that promotes the discovery of emerging concepts and factors without any preconceived notions.

3.1. Data collection and sample

Circular product design is a very new concept and has not been widely adopted in the industry. It is challenging to identify a large sample of firms that can provide relevant and valid data. Thus, the following sampling strategies were adopted in this exploratory study in order to collect reliable data. First, we used the member directory of 'Sustainable Business Network' to find local businesses, from which appropriate interviewees were identified and included in the sample. Sustainable Business Network is New Zealand's largest and leading organisation whose aim is to accelerate CE adoption. It consists of a pool of local businesses that have embraced the CE vision.

Second, we used individuals as the units of observation and analysis. We invited only those who had sufficient experience and knowledge of CE/sustainability and product design or supply chain management to ensure data validity. Our interview data captured broad working experiences in diverse industries and companies, which increased data diversity and avoided the potential bias issue. Moreover, we conducted interviews with four active CE researchers to incorporate relevant academic perspectives. These academics had a strong background in the industry and/or government consulting, which further strengthened the diversity of data and the reliability of the results.

In total, 15 semi-structured interviews were conducted in Auckland, New Zealand, in 2019. Sample characteristics are reported in Table 1. The median value of years of experience with sustainability and/or CE-related practices across interviewees was nine. The sample interviewees had broad working experiences in diverse industries and different companies. For example, Interviewee 1 had previously held managerial roles in three other firms before joining the current employer, a personal care products manufacturing company. Interviewee 5 had been an operations manager for nine years in a multi-national company before moving into the current role with a logistic service provider. The four academics who participated in the research represented three different academic disciplines: product design, environmental engineering, and supply chain management. The interviews with four CE researchers incorporated the relevant academic perspectives on circular product design in this study. The academics had an average of over 10 years of working experience in industry or consulting for governments. Three of them had appeared in the local media several times in recent years, speaking on sustainability/CE matters based on their subject expertise. These data show the sample interviewees had relatively strong knowledge and a practical background relating to the research focus. Their related experience in different organisations supported the exploration of diverse data beyond the organisations that these interviewees presently worked in.

The organisations from which the sample interviewees came are primarily small and medium-sized enterprises. Although many interviewees did not have the designation of 'design engineer' or 'supply chain manager' (as shown in Table 1), they all had been widely involved in product design activities and supply chain operations. In the process of selecting participants, all interviewees confirmed they had sufficient knowledge in product design and supply chain management. The interview data also showed that they were indeed very knowledgeable on the topic, which established data reliability and validity.

Interviews were conducted at the participants' place of employment. Each interview took approximately 60 minutes. Participants were emailed the interview questions ahead of the interview time so they could formulate and structure responses to each question.

The key interview questions are presented below:

1. *How do you see product design contributing to the success of the circular economy?*
2. *What opportunities does circular product design offer to businesses, consumers, and the environment?*
3. *What are the implications of circular product design for wider business, finance, IT, and other technologies, labour, and skills?*
4. *To what extent does moving towards circular product design require changes in supply chain processes, including sourcing and procuring materials, logistics, production, end-of-life product management, etc.?*
5. *What additional factors would help develop a framework for organisations to integrate product design and supply chain management for a transition to a circular economy?*

These interview questions were formulated based on the review of the literature on product design, SCM, and their strategic integration in a successful transition to CE as covered in Section 2. By reviewing the relevant literature, the research gap on how to operationalise the integration of product design and SCM was explored in this study. The interview questions were designed to acquire data for thematic analysis to answer the research question and thus cover this research gap.

Interview question 1 was used to probe an interviewee's viewpoint on the role of product design in a CE transition. It was designed to validate the importance of product design in transitioning to CE, as highlighted in the extant literature.

Table 1. Description of the interview sample.

Interviewee code	Job positions	Industry/Discipline sector	Years of experience in sustainability and/or CE
1	Director of Marketing and Digital	Personal care products manufacturing	17
2	Managing Director	Commercial flooring solutions	20
3	Business Manager	Textile rental services	7
4	Managing Director	Packaging manufacturing	10
5	Business Manager	Logistics services	18
6	Marketing Manager	Logistics services	3
7	General Manager	Recycling services	9
8	Research and Development Manager	Personal care products manufacturing	25
9	Managing Director	Personal care products manufacturing	2
10	General Manager	Personal care products manufacturing	2
11	Operations Manager	Personal care products manufacturing	2
12	Senior Lecturer	Academic in supply chain management and sustainability	6
13	Ph.D. researcher (formerly a university lecturer)	Academic in supply chain management and sustainability	9
14	Senior Lecturer	Academic in Environmental Engineering	20
15	Senior Lecturer	Academic in product design and sustainability	18

Interview question 2 was designed to identify the potential outcomes of circular product design, taking into consideration economic, environmental, as well as social performance. It sought to narrow the knowledge gap in the literature, that is, the lack of empirical investigation on the performance outcome of circular product design.

Interview questions 3 and 4 were designed to collect data that could provide direct answers to the main research question. The review of the literature showed that substantial changes were required in business, operations, technologies, and resources for implementing circular product design. Interview question 3 was used to determine the specific business-wide changes required based on the insights and experiences of the interviewees. Similarly, interview question 4 was designed to uncover the changes needed in supply chain operations (e.g. sourcing, production, distributions) for successful circular product design. These two questions directly addressed the key knowledge gap, which is the focus of this study.

Interview question 5 was used to capture additional factors relating to the integration of product design and SCM for CE. This open-ended question helped obtain data on the aspects that were not thought of by the researchers before the data collection. It also served to wrap up the interviews.

3.2. Data analysis

Thematic analysis was used to analyse the transcribed texts of interview data. This study followed the six-step approach of thematic analysis suggested by Braun and Clarke (2006) to avoid potential bias in analysis and findings. It started with reading and re-reading the transcripts to become familiar with the data. Second, coding was conducted. Each code was related to a specific concept that is central to the research question. In the coding process, labels were assigned to portions of the transcribed texts. For example, an interesting feature of 'buy services' or 'service economy' or 'hire services' was consistently found in the data. Thus, the code 'product-service system' was developed based on the conceptual commonality (e.g. delivery of services rather than ownership of products [Angelis, Howard, and Miemczyk 2018]). All relevant data were collated into this code. Codes were further refined and consolidated with similar conceptual aspects. Finally, 42 codes were established in this process. Third, potential themes were searched across the codes. The conceptual correlations across codes were analysed, and the closely relevant codes were collated into one potential theme. For example, while the codes 'product-service system' and 'sharing economy' present different operational aspects, they embed similar changes in the business models. Thus, a theme of 'business model innovation' was developed to incorporate these codes. This analysis process followed the criteria of 'internal homogeneity' and 'external heterogeneity', where data within themes have conceptual coherence and those between themes show distinct natures (Braun and Clarke 2006). In total, 10 potential themes emerged from the refined codes in this step.

Fourth, these themes were reviewed against the research question through a process of refining, upgrading, downgrading, and deleting. For example, a potential theme, 'CE skills requirements', also emerged from the data, showing the new requirements of labour skills and potential changes in employment. This study opted not to include this theme and its associated codes, as the human resources elements are not the focus of this research. Through this process, the number of themes was reduced to four. Fifth, the specifics of these four themes were analysed and refined, including their definitions, names, and associated codes. Finally, four themes were reported in this study according to the analyses above: *'end-of-life thinking in product design'*, *'business model innovation'*, *'sustainable organisational values'*, and *'circular supply chain management'*. The detailed results are provided in Section 4.2.

In order to ensure the reliability of the results, it is important to achieve thematic saturation whereby no new insights are generated by additional data. Guest, Bunce, and Johnson (2006) suggest that thematic saturation should occur after 12 interviews, although basic themes should be evident after six interviews. The sample size in this study affirms the threshold of the number of interviews. No new theme or code emerged after 12 interviews. Therefore the data collection stopped after conducting three more interviews.

Thematic analysis is to draw the homogenous responses in data by coding, and then conceptualises them into themes, showing the consistent factors from the data in answering the research question. Thus, this methodology relies on homogeneity in the data. The coding and themes that are developed in a systematic fashion from homogenous data are more likely to generate rigorous results. Therefore, this study reports the themes and codes derived from homogenous responses as major findings.

However, important divergent views were also captured in the thematic analysis. Specifically, the results showed the participants debating on the opportunities of circular product design in meeting short-run and long-run business objectives. These divergent views are reported in the next section prior to discussing the four common themes. The presence of the divergent views underscores the business risks when transitioning to CE and highlights the importance of the study's findings.

4. Results

4.1. Divergent views on the business opportunities of circular product design

The interviewees were asked to comment on the opportunities offered by circular product design to businesses, consumers, and the environment (interview question 2). The responses were unanimous that circular product design is beneficial to the environment as it provides firms with flexible environmental practices at later stages to improve the capacity of waste recovery and the utilisation of resources. Thus, resources loops can be largely slowed and closed. Nonetheless, there were divergent responses to the business opportunities of circular product design from an economic perspective. Five practitioners and two academics in the sample indicated that they had achieved or expected positive economic performance by adopting CE principles into product design and SCM. Two interviewees – a practitioner and an academic – were concerned with the negative impact of circular product design on economic viability. The other six interviewees believed that economic benefits are more likely to be in the long run, while businesses need to deal with the short-run challenges.

The positive responses to the business opportunities of circular product design were largely represented by a group of first movers in CE. The interviewees stressed that CE-oriented product design and SCM create competitive advantages, ranging from sustainability reputation, secure supply chain material flows, retained values of wastes, to energy efficiency. An interviewee from a personal care manufacturer stated that their business started up with sustainability thinking and had continuously adopted circularity practices. Therefore, their product design, logistics, production, and procurement were largely modelled with CE principles. In another example, one company positioned its business as a textile rental service provider (e.g. laundered linen rental to the hospitality industry), and had been running this business model over the decades. The CE literature has widely discussed service-based strategies in the transition to CE, or the 'product-service system', where manufacturers retain ownership of products and customers pay for the performance of products through leasing and service contracts (Batista et al. 2018; Masi et al. 2018). This textile rental service provider had a well-established product-service system in line with CE. As early adopters, these companies had cost-efficiency in CE implementations. Therefore, the economic and operational opportunities of CE were more likely to be readily visible.

The data also showed a concern with economic viability. The negative responses addressed the 'disruption' of CE to existing supply chain efficiency and uncertainty about consumer acceptance of circular products. The dominant linear and lean-focussed nature of supply chain operations are focussed on cost efficiency in materials flow from the upstream to the downstream. Production is largely outsourced to low-cost countries. Logistics has been developed to efficiently distribute the resources from the point of origin to the point of sale but not vice versa. Hence, businesses may find that shifting to the CE model disrupts supply chain efficiency. One managing director from a commercial flooring solutions business (e.g. commercial carpet tile and flooring) noted, 'I struggle to find a good circular economy product here … the manufacturer is still in China, and they have to get everything back to China. You've really got to have your manufacturing facilities everywhere'. Moreover, managers were concerned about the uncertainty of consumers' acceptance of circular products, and thus the low economic incentives of CE. One academic stressed that, at present, it was unlikely that a large group of consumers would be willing to pay higher prices for circular products – while consumers are naturally in favour of purchasing new products, they are concerned about the quality/performance/safety of, for example, refurbished products. One manager from a personal care product manufacturer noted, 'I'd say [consumers] are very important because ultimately if they don't change their purchasing behaviours, then we don't have anyone to buy the circular products or solutions that we create. So I would say very important but just a different role that they play'.

A group of interviewees from diverse industries had neutral responses to the economic impact of circular product design. While they expected performance improvement in the long run, the short-run challenges were acknowledged. The interviewees believed that a circular model is an innovative approach to improving operational performance. Nonetheless, the responses indicated the fruition of circular product design takes time and requires substantial and immediate investment and changes in resources, culture, and innovation. The interviewees added that circular product design and CE mainly focus on environmental performance with the addition of economic benefits. Thus, given the small government and industry support at present, the uncertainty is how CE-oriented firms can sustain themselves over short-run challenges to reach long-run benefits. An interviewee from a logistics service provider noted, '[T]he level of government [support] that deals with this sort of stuff is very low so there is no mandate'. A manager from a personal care manufacturer added, 'Once you get to big businesses and you've got investors and shareholders. It's very tricky. When times are tough, profit is god'. One interview participant confirmed, 'I mean [CE] is the future. It's smart business. But I don't know how many people do it because it's costly and challenging and if everyone is about the economic bottom line, why would you do it?'

The divergent responses demonstrate the business uncertainties surrounding the adoption of circular product design. Many organisations, especially large companies, have historically developed their product design strategies, business model, supply chain operations, and organisational values based on linear operations. Most businesses are inevitably challenged by the short-run costs of circular product design. Because of its substantial modifications of operations and supply chain redesign (Masi et al. 2018), circular product design focuses on long-run environmental and economic returns. This increases financial liability during the long process of implementation, and a systematic approach is needed that supports the business transition to CE while managing the associated risks.

4.2. Common themes

The analysis of data yielded four common themes: *End-of-life thinking in product design*, *sustainable organisational values, business model innovation,* and *circular supply chain management*. Figure 1 shows the thematic map of the four themes and their associated codes. Further analysis of the most common words used by interviewees yielded the results presented in Table 2. This table illustrates the frequency of keywords used by interviewees. Stop words such as 'a', 'and', 'so' etc., were removed from the analysis.

4.2.1. End-of-life thinking in product design

The 'end-of-life thinking in product design' theme encapsulates the responses to sustainable options for each product at the end of its lifecycle. A product's end-of-life options are largely determined in the product design phase; therefore, it is difficult to change the product's attributes, resource allocation, and infrastructure once the product design is finalised. Products designed with end-of-life intentions provide flexibility, efficiency, and effectiveness, thus allowing the embedded resources to be repurposed and minimising the amount of waste being sent to landfills. The interviewees believed that the lack of end-of-life options is a major source of waste generation, and product designers can provide potential solutions if they embrace end-of-life thinking. This theme includes six codes, as explained below.

Design for sustainability relates to a product design strategy that extends product life by incorporating environmental and social benefits. It follows the cradle-to-grave approach from the linear economy (Mayyas et al. 2012). While the interviewees referred to 'sustainable products' and 'circular products' interchangeably, all were aware of the difference between the two terms. This study additionally coded '*circular product design*' and contrasted it to DfS. A business manager from a textile rental services business stated, 'So, product design is an important part of the CE, and we incorporate it into our business model. We partner with other organisations that work on good responsible sustainable product design'.

Resource efficiency refers to a firm's ability to use resources to their maximum efficiency. The improvement of resource efficiency has been widely called for in sustainability policies and regulations, including in the Europe 2020 strategy (Tukker 2015). Business firms are required to adapt to the policies and explore the competitive advantages through efficient use of resources. All interviewees demonstrated

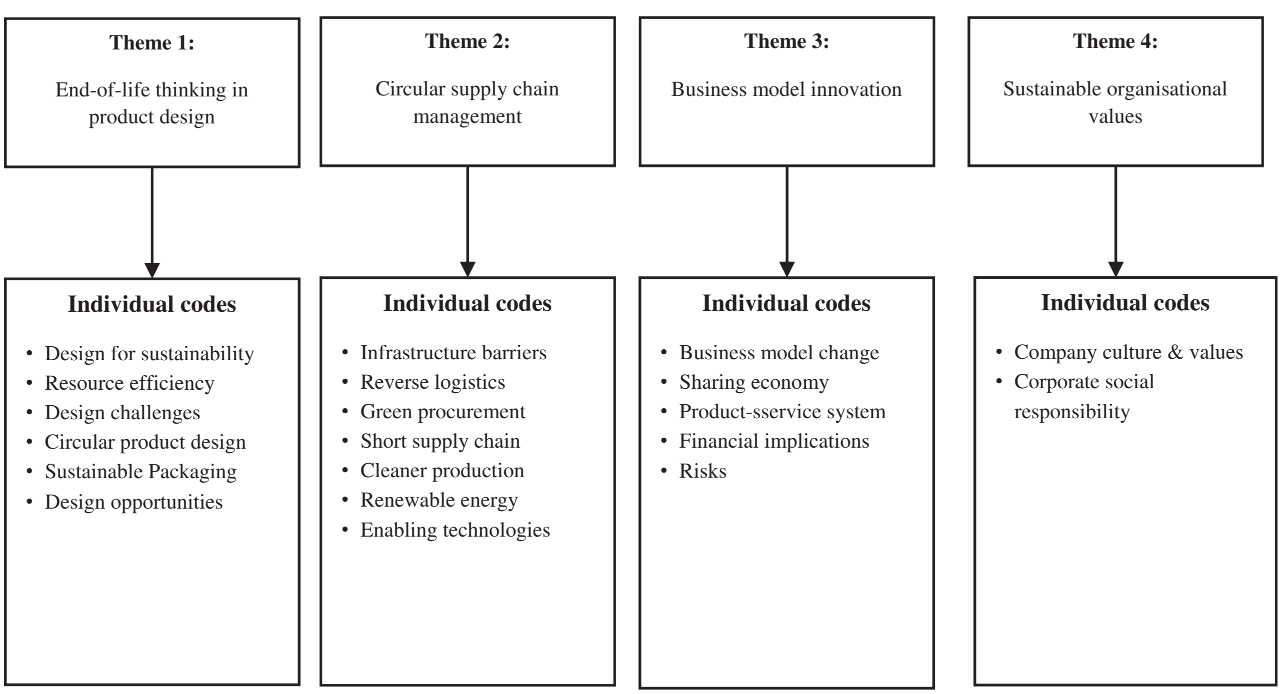

Figure 1. Thematic map of the main themes and codes.

Table 2. Word frequency in the coding of thematic analysis.

Word	Frequency	Weighted percentage (%)	Similar words
Product	438	1.39	Product, product', product's, products
Thinking	397	1.26	Think, thinking
Circular	365	1.16	Circular, circularity
People	358	1.14	People, peoples
Change	309	0.98	Change, change', changed, changes, changing
Business	293	0.93	Business, businesses
Economy	271	0.86	Economies, economy
Design	253	0.80	Design, designed, designer, designer', designers, designing, designs
Recycling	168	0.53	Recyclability, recyclable, recycle, recycled, recyclers, recycles, recycling

good knowledge of resource efficiency and expressed concern over the depletion of natural resources. The interviewees felt the global economy should collaborate in improving resource efficiency at both the macro and micro-level. A manager of research and development in personal care product manufacturing stated that 'using less and using it better has to be done'.

Design challenges capture the critical issues in innovative product design. These challenges range from technical constraints, resource availability, regulatory barriers, and design costs (Bocken et al. 2016). The data showed all the interviewees had experienced some form of design challenge. Eight of the 11 practitioners and two of the four academics in the sample agreed that there is a lack of infrastructure that supports the designed repurposing of products at the end of the lifecycle. In addition, sustainable products are beyond traditional product design concepts. The sustainability attributes increase design costs and their associated production costs. A director of marketing and digital from a personal care product manufacturer stated, 'It's just the costs. I mean the practical challenge for businesses is the costs. The costs of changing the way you do business. The cost of changing those supply chains or the cost of redesigning products is a fundamental challenge that will stop some businesses'.

Circular product design encapsulates design for product integrity (i.e. preventing and reversing obsolescence at a product and component level) and design for recycling (i.e. preventing and reversing obsolesces at a material level) (Den Hollander, Bakker, and Hultink 2017). The data showed that businesses were very enthusiastic about circular product design and the benefits it has for the environment and society. The interviewees regarded the linear production model as a major source of pollution. Moving towards circular product design was seen as a promising approach to waste reduction and efficient use of resources. The business manager from a textile rental services business noted, 'The reuse of products multiple times over means waste costs reduce because we aren't throwing out so much stuff now'.

Sustainable packaging refers to the development and use of packaging solutions that incorporate sustainability principles (e.g. packaging reduction and recycling). Packaging materials follow a similar lifecycle to products and are most likely used once and then discarded into landfills (Svanes et al. 2010). The interviewees acknowledged that excessive use of packaging was as environmentally harmful as unsustainable products. However, most packaging has complex materials to support transportation and the use of the products, and thus are difficult to recycle. Simplifying and standardising packaging would facilitate the development of infrastructure for packaging recycling. A business manager from a logistics business stated, 'I think standardisation in packaging would help with this issue. If there were global standards for packaging, then recycling could happen more easily'.

Design opportunities relate to opportunities firms can leverage from innovative design. Firms that capture the ability of innovative design are found to effectively develop competitive advantages (Swink and Song 2007), including reputational assets, preservation of resources, and new avenues for revenue. Two interviewees confirmed the achievement of competitive advantages in their businesses. However, both businesses were 'early entrants' to the market of circular products. This is in line with the findings presented in Section 4.1 that there is a correlation between those who are first movers and those who are positive about business opportunities arising from circular product design.

4.2.2. Circular SCM

The data highlighted interviewees' understanding that supply chains need to be redesigned to incorporate CE practices. Green procurement strategies should be adopted to improve environmental and social performance in sourcing materials. Cleaner production practices are required to reduce pollution and reliance on fossil fuels. Supply chains can be shortened by decentralising manufacturing, which reduces the transport distances of goods and services, and thus carbon emission in logistics. Infrastructure needs to be developed to facilitate reverse logistics. Renewable energies should be used throughout the entire supply chain. The data showed that managers were aware that traditional linear supply chains are unable to support the reverse flow of resources. The circularity within and across supply chains should be evolved to enlarge the integrations of operations in a wider scope. The theme 'circular supply chain management' was developed from seven codes based on 170 related responses. The associated codes are introduced below.

Infrastructure barriers refer to all structures required for processing and facilitating the circular flow of resources in the supply chains, including transport, energy, factories, and systems (Ness 2008). An infrastructure in favour of CE is required to support the circular transfer/share of waste and its related information. All responses in the data stated concern with the lack of infrastructure facilitating CE implementation. A manager from a personal care product manufacturing company stated, 'Now one of the other things is the reverse supply chain, so when something goes out, how does it get back? Thus, … one of the infrastructure barriers that we've got is we don't have the infrastructure to return goods'.

Reverse logistics encapsulates activities that occur at the end of a product's lifecycle to recapture resources' value (Dekker et al. 2013). The data showed businesses' belief that reverse logistics is instrumental in capturing the retained values in wastes but that these are not highly utilised. As the data highlighted, return costs, lack of infrastructure, and misconceptions concerning retained values are the major barriers to utilising reverse logistics. A business manager from a textile rental services business stated,

> Reverse logistics has always been an issue because generally, freight costs more for sending goods in the other direction and it requires a change in the infrastructure and in the processes. The problem with returning goods is businesses do not see the value in the waste and so they do not invest in getting their products back at the end of their lifecycle but a significant margin can be made on return trips because of the need for trucks to backfill on their return route. Businesses only see the cost of transport and not the value in the returning of the material.

Green procurement involves purchasing practices that include the evaluation and monitoring of suppliers' environmental and social performance (Blome, Schoenherr, and Eckstein 2014). The data showed that businesses believed that green purchasing practices are an effective force in improving suppliers' sustainability performance. Present procurement management focuses on traditional operational performance (e.g. costs and speed). If downstream firms focussed on positive environmental and social impacts in production, there would be a knock-on effect on their suppliers. An academic of environmental engineering stated that 'businesses have the power to force change throughout the supply chain by using their purchasing power and enact change on suppliers'.

Short supply chain relates to creating a regional network that connects producers with consumers (Marsden, Banks, and Bristow 2000). A short supply chain focuses on the reduction of supply chain complexity and length by removing intermediates from the process. Goods are produced in a geographical area and then sold in the same region, which reduces the transportation between production and consumption. Thus, supply chains should be shortened, and manufacturing should be decentralised in order to achieve a reduction in pollution and fossil fuel usage. A managing director in a commercial flooring solutions business stated, 'You've really got to have your manufacturing facilities everywhere. Small manufacturing facilities. Local. Then just use the Hub and Spoke shipping models. Businesses need to change to local and bring manufacturing back to New Zealand'.

Cleaner production refers to an organisation's ability to minimise or mitigate negative environmental impacts in manufacturing processes. By using preventative environmental protection initiatives and lifecycle analysis, an organisation can analyse its use of resources and energy to minimise waste and emission outputs (Kjaerheim 2005). The data showed that businesses regarded manufacturing as a major source of waste and pollution. They believed manufacturers should fundamentally change their approaches to sourcing materials and production. Cleaner energy and renewable resources must be increasingly used in production. The manager of the commercial flooring solutions company stated that 'it's the manufacturers who really need to understand the design side to make their products circular. The production processes that manufacturers are using are harmful to the environment. Products are not being designed to be circular but rather for single-use and easy to throw away'.

Renewable energy refers to energy sources, including solar, wind, hydro, and geothermal heat. The interviewees maintained that the use of fossil fuels is a major source of environmental damage. Supply chain partners need to collaboratively explore the opportunities in using renewable energy to achieve environmental and economic benefits. An interviewee working on SCM research stated, 'Energy is a very important factor to CE because, for products and transport, they need to be driven by renewable energies. Moving from fossil fuels to solar or wind power is very important to keep the CE operating in a circular manner'.

Enabling technologies relates to the utilisation of technologies that can drive or enhance the capabilities of SCM (Tjahjono et al. 2017). Industry 4.0 develops cyber-physical systems, the internet of things (IoT), cloud computing, and artificial intelligence, which support the technical development of circular supply chains. While five practitioners and two academics in the sample felt the cost of some emerging technologies was out of reach for most firms, all sample practitioners indicated their companies had adopted certain new technologies to improve operational efficiency. One academic stated, 'Technology is essential for any business activities. We cannot isolate business activities from technology. Now it is integrated. Whatever firms want to do, they have to use technology, but what and how makes a big difference'.

4.2.3. Business model innovation

The 'business model innovation' theme was drawn from the data because interviewees noted the need for dramatic changes in business strategy. There are business risks and uncertainty associated with the transformation of business strategy. In particular, CE principles require fundamental changes to move from a long-standing linear business model to unprecedented circular operations. Hence, a business model innovated in line with CE principles must be created to support the transition. Also, such business model innovation can create intangible resources and products/services with a circular nature, representing rare and inimitable assets that create competitive advantages. All interviewees noted the requirement for firms to adopt an innovative business model that is conducive to the CE principles. Five codes were derived to generate the 'business model innovation' theme as presented below.

Business model change relates to organisations' adoption of business models that suit their type of business and encapsulate circular principles (Planing 2015). The present business models are largely geared towards the linear economy. Firms are required to upgrade business models with equal importance placed on the environment, society, and profitability. One manager from the personal care product manufacturing industry expressed frustration at the current linear business models, stating that, 'I think the reality is that we can all do better. We must do better. We must completely change. I think the issue is that it's not about incremental change. It is not about doing less bad. It is that we need to fundamentally redesign our systems, our processes, our products, our services such that we are actually doing something circular'.

Sharing economy refers to the sharing of resources and assets between organisations in a business-to-business (B2B) or business-to-consumer (B2C) context. A B2B perspective indicates co-opetition, where competitors collaborate and share resources for mutual benefits (Luo 2007), given that the competitors are more likely to have a high level of uniformity in product/service specifications and markets. The interviewees stressed that CE creates an opportunity for widening scope in sharing resources (e.g. within and between supply chains), which is commonly restricted in the linear model. These interviewees regarded sharing as a prudent way of gaining access to resources that they would not otherwise have access to. A general manager of a personal care product manufacturer stated, 'Sharing is a big part of our industry. We can't handle this by ourselves. We must be realistic. We don't have the infrastructure or the capital to make changes happen rapidly enough. We intend to be in the future but, that might be 15 years away'.

Product-service system (PSS) denotes that firms offer products to rent or lease as opposed to selling (as discussed earlier in Section 4.1). Firms retain ownership of the products and ensure they are maintained to the highest operational level, which prolongs the life of the asset (Mont 2002). Two interviewees indicated that their businesses were using the PSS model. They believed that firms financially benefit from such an innovative business model, although the management of customers' proper use of the products needs to be improved. One academic noted, 'Now we've got the whole situation where the business will take responsibility for the product, and you pay for the service .... The business takes back and reuses the materials because the materials are really valuable'.

Financial implications relate to trade-offs between economic viability and environmental and social sustainability commitments. While business firms are willing to make sustainable and long-term changes, there should be no harm to their financial health. The interviewees noted the connection between economic viability and environmental and social performance. If an organisation has the financial capabilities, it can invest in new technologies and employ good staff. A general manager from a personal care product manufacturer stated, 'To challenge the bottom line. You're still focussed on making money because you need to make money in order to make change … we never downplay financial sustainability because if we're not financially sustainable, then we've got three staff members who are no longer sustainable for their family. So, we have to be financially sustainable'.

Risks refer to business risks associated with significant changes in business activities/models/systems. All practitioners and two academics in our sample noted the business risks were related to immediate and substantial investment and business transformations. A director of marketing and digital from a personal care product manufacturer stated, 'Because in changing from one system to another, there is a significant cost to the business. Therefore, if they don't make that workable, there is no incentive for businesses to change, or there is disincentive even if the intention is there'.

4.2.4. Sustainable organisational values

Managers in the sample firms largely noted that sustainable culture and values in the organisation-wide context are necessary to support the successful development and implementation of CE practices. Top management's support for environmental and social initiatives is the top-ranked driver for sustainability management (Sroufe 2009). The top management team should upgrade organisational vision and missions in line with CE principles, which can substantially reduce resistance to the additional workload caused by CE development and improve employee buy-in of CE implementation. The following two codes are included in the theme.

Company culture and values refer to a firm's ability to create, implement, and maintain culture and values that are in line with its company strategy (Flamholtz 2001). The data showed that businesses strongly supported the creation of a 'good' culture and values within their organisations. Six practitioners found that their company culture and values were what made their company unique and gave it a competitive advantage. Top management should champion such culture and values, and staff should be expected to hold consistent visions. The research and development manager from a personal care product manufacturer was very enthusiastic about their company culture and values, and stated, 'We are lucky because our business is owned by a family, and a decent family and they do have concerns, and they want to do the right thing. So, management and the people in higher positions in the company are quite important in driving the vision and culture'.

Corporate social responsibility (CSR) relates to the corporate policies that govern ethical decision-making around social and environmental factors (Dahlsrud 2008). The data showed businesses found it important to be good corporate citizens, and especially important to participate in the transition to CE at the national level. Business firms have not been sufficiently responsible for waste management while producing massive global wastes. The data showed that firms were aware that good CSR practices create substantial reputational assets. Companies also felt obligated to be good corporate citizens in order to provide a sustainable future for their businesses and society. A managing director from a packaging manufacturer stated, 'Corporate social responsibility is driven by organisations. The leaders of these companies understand the impact they have and don't want to destroy their company image'.

5. Discussions

5.1. General propositions

The presentations of the above themes demonstrate that end-of-life thinking in product design, business model innovation, sustainable organisational values, and circular SCM play important roles in developing and implementing CE. Thus, four propositions are developed in this study.

A stronger connection between design strategies and end-of-life product and waste management is required. As found in this study, businesses are increasingly incorporating environmental and social attributes into their design activities, using, for example, DfS. However, the nature of the linear approach embedded in DfS weakens the flexibility and capacity of end-of-life product and waste management. A product is highly flexible to incorporate specific attributes at the design stage. It is essential to integrate end-of-life options into the product design to maximise the opportunities for waste reduction, restoration of technical materials, and regeneration of biological nutrients. Circular product design emerges as an effective approach, creating a stronger linkage between product design and end-of-life product and waste management. The hierarchical strategies (e.g. design for product integrity and design for recycling) in circular product design provide multiple methods for resource circularity (e.g. repair, reuse, remanufacturing, refurbishment, and recycling) at the end of the product life cycle. Furthermore, resource efficiency and sustainable packaging are key aspects in end-of-life thinking that need to be considered in the product design stage. Thus, this study proposes the following:

> Proposition 1. End-of-life thinking is required in re-engineering product design activities in order to design circular products.

The finding of design challenges in this study demonstrates the necessity of extending the traditional product design concept to the supply chain context. The traditional boundary of product design is within individual firms, particularly within the design functions. Nonetheless, emerging barriers to integrating design for circular products and end-of-life product and waste management (e.g. infrastructure and reverse logistics), as found in this study, evidence that a supply-chain-wide configuration is required. A circular supply chain can strengthen the implementation of circular design concepts at the end of the product life cycle. In turn, the reverse information and material flow from the point of sale provide product designers with innovative ideas for continuous improvement. This study found that firms can engage circular thinking in the aspects of reverse logistics, short supply chain, green procurement, cleaner production, and renewable energy, as part of supply chain redesign initiatives. The development of Industry 4.0 allows enabling technologies to overcome supply chain complexity in developing resources circularity. Hence, the following is proposed:

> Proposition 2. Circular thinking is required in redesigning supply chain processes in order to recover value from circular products to achieve resource circularity.

This study's findings show urgency in upgrading business models to fit a circular supply chain design. Two innovative approaches, sharing economy and PSS, are believed to be effective business models. Sharing economy expands traditional vertical collaboration to horizontal relationships in the acquisition of critical resources. The diverse forms of resource exchanges provide new demand-supply relationships and support open-loop supply chain circularity. PSS can be developed across multiple supply chain partners. The ownerships of recoverable components can be retained by an original equipment manufacturer, using a leasing model to its retailer. The upstream component suppliers can also use a leasing model targeted at this original equipment manufacturer. Their professional maintenance and product expertise support the search for new opportunities for resource circularity at a supply chain level. In addition, the findings show there are concerns about business risks when enacting radical business model changes. The economic viability is highlighted in the data as the main business objective and a causal factor in sustainability investment. PSS is likely to provide businesses with innovativeness to accommodate new design strategies and maintain core business activities. Therefore, the following is proposed:

> Proposition 3. Innovative thinking is required in creating sustainable business models that are economically viable and can unlock the potential of circular products.

The integration of end-of-life thinking, circular thinking, and innovative thinking into daily business activities for a CE transition, as discussed above, must be grounded on a solid organisational commitment to sustainability. Sustainable organisational values are essential for securing the successful implementation of these mindset and culture changes. A company's CE culture and values demonstrate commitment at the top management level to the organisation-wide implementation of CE practices. They strongly motivate employee buy-in and the innovativeness of, for example, product designers and operations/supply chain managers. Also, a consistent CSR policy that explicitly delineates a CE roadmap and practices provides a systematic approach to monitoring progress. It also develops the company's dynamic capabilities in the business community and the ecosystem. Meanwhile, publicising firms' commitment through CSR policy can generate significant reputational assets to support short-run investment in the transition to CE. Hence, the following is posited:

> Proposition 4. Sustainable organisational values are the cornerstone of a successful transition to CE.

5.2. Operational framework

Based on the propositions discussed above, this study proposes a framework, as presented in Figure 2, to guide circular product design and the operationalisation of CE. The framework depicts how sustainable organisational values and a CE vision can be operationalised. The operational system has four components that interact with each other: circular

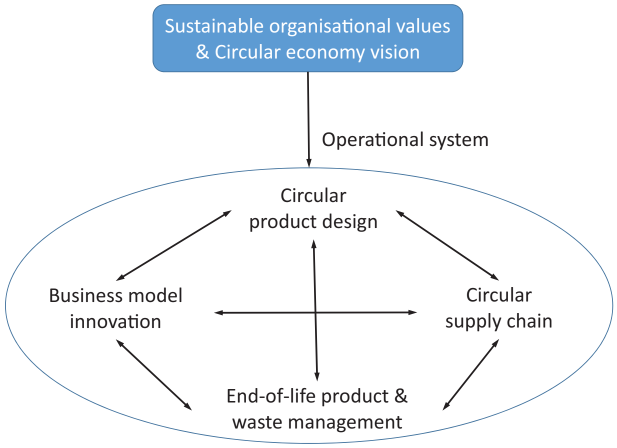

Figure 2. An operational framework for integrating product design and SCM for CE.

product design, end-of-life product and waste management, circular supply chain, and business model innovation.

A transition to CE and circular product design must start from a strong commitment to sustainable organisational values and a CE vision. Top management must lead an organisation to assume corporate social responsibilities to care for the environment and society. Moving from a dominant linear economic model to CE requires fundamental changes in many aspects of a business. Resistance to change is often one of the greatest challenges in business improvement initiatives as people are used to the traditional ways of thinking and doing business (Zhang et al. 2016). Unless the organisational values and vision are correct, it will be very difficult to overcome challenges effectively and decisively in the implementation journey.

Circular product design is the starting point of operationalising CE at a firm level. As clearly established in the thematic analysis, end-of-life thinking is required for designing circular products. Product designers must consider the end-of-life product and waste management options at the design stage. Furthermore, improvement in end-of-life product and waste management capabilities developed through business model innovation should also inform circular product design. At the start and the end of the product lifecycle, circular product design and end-of-life product and waste management need support from the circular supply chain to keep resources in circulation. They also need business model innovation to facilitate a paradigm shift from a dominant linear economic model to CE in order to make the transition economically viable. A sustainable product-service system and the sharing economy are some of the innovative business models which can be considered. With increasing capabilities in circular SCM and innovations in business models, circular product design and end-of-life product and waste management may have more options available for operationalising CE. Note that business model changes are likely to require a change to circular SCM as well. There are clearly interplays (indicated by arrows in Figure 2) among all the four components of the CE operational system.

5.3. Theoretical contributions

This research makes two academic contributions. First, this study extends the literature on supply chain operations for CE from the perspective of circular product design. There is increasing acknowledgement of the need to adopt circular supply chain operations in the transition to CE (Batista et al. 2018). However, circular SCM has many operational barriers, especially the challenges of coordination and collaboration among supply chain members (Mangla et al. 2018). This study adds a new dimension to circular supply chain collaboration by integrating circular product design. It is proposed that product design with end-of-life thinking is an effective starting point to develop circular SCM in the transition to CE. Using a lifecycle assessment, the design of circular products can be extended from within firms, traditionally in a linear model, to a supply chain level in a circular system. Supply chain operations of sourcing, production, logistics, and waste management can be incorporated through the collaborative design of circular products. The shared information on product attributes across supply chains, in turn, improves the circular information and material flows of disassembly and value recovery.

Second, this study provides an integrated framework through circular product design to operationalise CE and circular supply chains. Previous studies have investigated business models (Yang et al. 2018), supply chain design (Bernon, Tjahjono, and Ripanti 2018), and sustainability drivers (Masi et al. 2018) in the context of CE and circular supply chains. While these studies supplement the literature separately, there is a lack of a systematic framework that integrates these core factors to operationalise circular supply chains and CE. This study explores the effective role of designing circular products in circular supply chains. The circular product design approach can improve the efficiency and effectiveness of circular supply chain collaboration and coordination, support business model innovation (e.g. PSS), and thus increase the flexibility of managing end-of-life products and wastes. The present study also incorporates sustainable organisational values and CE vision as an overall driving force, advancing the operational system framework from a strategic viewpoint. The interplays among the components in the operational system provide a novel insight into CE adoptions from the perspective of integrated circular product design and circular SCM.

5.4. Practical implications

Five practical implications can be derived from the findings. First, firms need to strategically manage the short-term cost of CE adoption to achieve long-term benefits, while wider communities should also provide support to firms. This study found that cost is a major concern in CE adoption. There are inevitable and immediate costs in designing circular products (e.g. new infrastructure). There may also be an increase in transaction costs, as circular product design involves various stakeholders (e.g. suppliers) in changing the present linear design (De los Rios and Charnley 2017). However, there are also apparent long-term benefits, for example, procurement cost reduction due to the use of secondary resources, and the decrease of energy consumption due to maximised resources yield (Bocken et al. 2016). Firms need to be well-prepared for looming costs in order to achieve these long-term benefits. Firms may showcase their circular products in the search for financial and technological support from governments, consumers, and non-governmental organisations. Support from wider society, including policymakers and consumers, is necessary for firms to deal with the cost pressures. True sustainability should include economic viability as an important factor in human development (Pagell and Shevchenko 2014).

Second, shortening supply chains that operate within regions rather than on a global scale can reduce environmental impacts and supply chain costs. For example, short supply chains could operate within the regions of Australasia, North America, Asia, and Europe. By regionalising supply chains, firms can reduce the transport distance between supply chain actors and reduce the number of intermediates within the supply chain. A short or regional supply chain minimises the distance of resources and the movement of products between sourcing, production, and customer. Furthermore, by removing intermediates from the supply chain, fewer firms need to handle the products. A pragmatic approach must be taken to the regionalisation of supply chain management because supply chains are currently globalised to leverage a cost-effective supply of resources, labour, production, and transport. Regionalisation of supply chain management must only be undertaken if the environmental, social, operational, and resource costs are reduced or offset by the reduced logistics costs.

Third, SCM needs to be transformed with circular thinking. Waste occurs when resources are not able to be used and must be disposed of. Through closed- and open-loop supply chain design, resources can be utilised to their maximum potential (Farooque, Zhang, Thürer, et al. 2019), which requires a high level of supply chain collaboration with inner and outer supply chain partners. The information flow must be upgraded to include wastes and their component data, while the risk of such additional information-sharing in competitive markets needs to be managed. Waste warehousing, transporting, and supplying functions need to be designed at the supply chain level. There are 'focal firms' in supply chains, which commonly rule or govern the supply chain, provide direct contact to customers, and design the product or service offered (Seuring and Müller 2008). Given their broad vision of supply chain operations and the careful use of power, focal firms can strategically lead the establishment of a closed-loop supply chain and initiate the resources transactions at the industry level and across different supply chains. A full circulation of resources is more likely to be accomplished with SCM upgraded with circular thinking.

Finally, the rapid development of technologies should be integrated to facilitate circular supply chain operations. Industry 4.0 provides the essential technological underpinning to improve supply chain integration and support the adoption of CE at the supply chain level (Zhang et al. in press). Through cyber-physical interconnection and sensors that collect big data, smart technology has allowed supply chains to gather real-time information that allows management to make informed decisions. The use of robotics, IoT, and artificial intelligence allows processes to be automated, which reduces inventory shortages and human errors while optimising production and logistics activities (Pan et al. 2015). Blockchain technology can be used to overcome the challenges of collecting reliable data when conducting a lifecycle assessment, enabling better integration of supply chain data and material flows for improving sustainability performance (Zhang et al. 2020).

5.5. Policy implications

A framework of supportive policies should be established in firms' use of circular product design and circular SCM strategies. At present, governments mostly apply coercive forces (e.g. regulations) rather than supportive forces (e.g. financial support) on business' sustainability transformation. Interviewee responses in this study show that this policy route creates a 'transactional relationship' between governments and businesses that intend to adopt CE principles. Governments' involvement in industrial CE practices is low, while the regulatory pressure is high. Given the substantial investment required in CE adoption, some businesses have to either struggle with financial constraints or perform 'greenwashing' in compliance with regulations. Governments should improve business incentives for CE practices by using, for example, taxation policies. Businesses embracing CE should be encouraged by tax reliefs and subsidies, while unsustainable businesses should be discouraged by additional levies. For example, 'Pigouvian tax' (Sørensen 2018) and tax on virgin materials (Schlosser, Chenavaz, and Dimitrov 2021) are found to effectively motivate firms to adopt CE practices. These similar government policies would allow the competitive advantages of CE-oriented businesses to emerge quickly.

Moreover, governments should endeavour to improve the acceptance of circular products in society. As discussed earlier, consumers' acceptance of circular designed products is not high. One of the concerns is the quality, performance, and safety of these products. Governments could involve industrial associations to develop industry-wide quality standards and warrants for circular products, which could significantly improve consumer confidence. Also, government communications could increase society's awareness of the environmental benefits of circular products, which will serve to improve consumer acceptance.

Finally, governments could support the growth of secondary markets. The wastes or by-products of one organisation could be exchanged to become the resources of another organisation. This exchange is more likely to be across industry sectors and supply chains, where more diverse reuses of wastes or by-products can be explored (Farooque, Zhang, Thürer, et al. 2019). Businesses are more likely to rely on governments' intermediary role to connect to different sectors, due to the limited scope of each supply chain operation.

Hence, governments should proactively bridge the exchanges across supply chains, motivating the formation of larger circular loops and improving business efficiency in the quest for resource circularity.

6. Conclusion, limitation, and future research

This study investigated the integration of product design and SCM for a transition to CE. In total, 15 interviews were conducted with experienced practitioners and researchers in order to collect and analyse data using thematic analysis. Four important propositions were developed: *end-of-life thinking with product design, business model innovation, sustainable organisational values, and circular SCM*. A conceptual framework was developed based on the interplay of the themes above as an operational system for business firms' CE adoption. This operational system provides guidance to product designers, managers, and researchers to advance the CE cause at the supply chain level.

Despite its original contributions, this study has its limitations. Circular product design is a new concept that has not been widely adopted in the industry. This New Zealand-based exploratory study interviewed only the most knowledgeable experts to ensure data quality, and had to accept an inevitable trade-off of a relatively small sample size. Nonetheless, data saturation was observed, so the reliability of the results is not a concern. With the increasing adoption of circular product design in the industry, future research should attempt a larger sample size. Researchers could also use organisations or supply chains as the units of analysis. Different methods may be employed, for example, case study or survey. It is also worthwhile investigating circular product design in a variety of research contexts where the cultures and institutional infrastructure are different. Moreover, the interviewees in this study worked across diverse industry sectors, which was beneficial to the generalisability of our findings. However, the limited sample size did not justify an analysis of differences across sectors. Future research may extend this study by investigating industry-specific attributes relating to the operational framework developed in this study. Furthermore, future studies can be aimed towards developing design frameworks to operationalise circular product design. Much attention has been paid to the concept of circular product design, but little research has provided guidance on 'how' to design circular products. Further research needs to be conducted on understanding how the price of circular products can become comparable to linear products. Finally, tools need to be developed for enabling circular product design.

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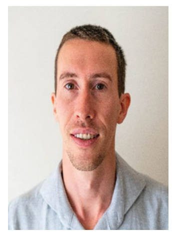

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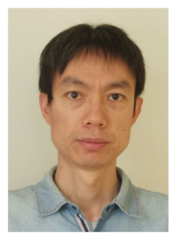

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