CRANFIELD UNIVERSITY

CARL-CHRISTIAN KÜHL

PRODUCT-SERVICE SYSTEMS AND SUPPLY CHAIN CIRCULARITY: A MIXED METHODS INVESTIGATION

SCHOOL OF MANAGEMENT
PhD in Leadership and Management

Doctor of Philosophy
Academic Year: 2017-2021

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This thesis is submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy
(NB. This section can be removed if the award of the degree is based solely on examination of the thesis)

To my parents, Sima and Jörn-Sven

ABSTRACT

The circular economy (CE) aims to create economic and environmental benefits, by keeping products and materials at highest utility and value through long-lasting design, repair, reuse, refurbishment, and recycling. CE transformation results in a slowing, closing, and narrowing of resource loops, which is also termed supply chain circularity (SCC). Product-service systems (PSSs), in which manufacturers meet customer needs by providing services instead of selling products, are considered key business model innovations for increasing SCC. However, there is a lack of empirical evidence on whether PSSs actually contribute to SCC or whether they are a facade behind which linear 'business-as-usual' continues. This PhD thesis conducts a mixed methods investigation of the relationship between PSSs and SCC. It consists of three papers: 1) a systematic literature review (SLR) of 67 papers; 2) a quantitative survey of 206 machinery and equipment manufacturing firms in the United Kingdom (UK); 3) a multiple-case study of three manufacturing firms in Germany and the UK.

The findings show that: 1) result-oriented PSSs have the highest potential contribution to SCC, followed by use- and finally product-oriented PSSs; 2) use-oriented PSSs are limited in contributing to a slowing of resource loops through refurbishment; 3) PSSs' contribution to SCC depends on enabling and inhibiting contextual factors, especially organisational ones. In sum, this PhD study argues that PSSs can only catalyse the transition from a linear to a CE if an enabling business context is established. The PhD makes three key contributions to theory and practice: 1) it provides empirical evidence that PSSs do not inherently contribute to a slowing of resource loops; 2) it develops an empirically validated framework of enablers and barriers, particularly organisational ones; 3) it extends the SCC concept, by developing survey items and offering a first attempt at theorising how the transition to SCC occurs during a manufacturer's servitization process.

Keywords: Circular economy, product-service system, supply chain management, servitization, case study, partial least squares structural equation modelling (PLS-SEM)

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This thesis is first and foremost dedicated to my parents, Sima and Jörn-Sven. You both are my unassailable idols in life and have instilled me with an intellectual curiosity as well as a desire to make the world a slightly better place. I am very honoured to follow in your footsteps and to also be called a 'Dr'. Without your enduring support, I would have never made it this far - thank you! I would also like to thank my wonderful fiancée, Estephania. Meeting you at the Circ€uit autumn school in Grenoble was undoubtedly the highlight of my PhD journey. Your calm demeanour and words of encouragement have been the Ying to my Yang. A warm thank you also to my brother, Georg, who inspires and challenges me to be a better person and to my uncle, Wadih, for the lovely London walks and for being a mentor and a friend.

On the academic side, my special thanks go to my triumvirate of supervisors: Prof Michael Bourlakis, Prof Emel Aktas, and Dr Heather Skipworth. You complemented each other perfectly and always found the right way to nudge me forward. Michael, you were a role model for accountability and helped me to think more strategically about my work. Heather and Emel, you both helped me gain clarity in my thinking and writing as well as rigour – in both case study and survey methodology. Moreover, you showed me the value of constructive and specific feedback as well as the importance of caring for the well-being of your students. I would also like to thank my panel: Mike Bernon for his challenging questions and Dr Denyse Julien for giving me the opportunity to find a passion in teaching. In addition, a very warm thank you to Dr Hendrik Reefke and Dr Hamid Moradlou for their friendship and support over the past four years – I already miss the laughs that we shared. Finally, Prof Benny Tjahjono for initially bringing me to Cranfield and for believing in me.

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A very special thank you to my Cranfield PhD colleague Denghao Wei. You were my unofficial fourth supervisor, a voice of pragmatism and clarity, when mine was lost. I hope to see you again soon, my friend – either in China or in Europe. Finally, my thanks go to all of the practitioners that have kindly supported this research through interviews. Collecting data was the biggest challenge in this PhD and I am very grateful that you took the time.

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LIST OF ABBREVIATIONS

AVE	Average Variance Extracted
CE	Circular Economy
EU	European Union
HTMT	Heterotrait-Monotrait
NRBV	Natural Resource-Based View
PLS	Partial Least Squares
PSS	Product-Service System
RBV	Resource-Based View
SCC	Supply Chain Circularity
SCM	Supply Chain Management
SEM	Structural Equation Modelling
SLR	Systematic Literature Review
UK	United Kingdom
VIF	Variance Inflation Factor

1 Introduction

Environmental crises such as climate change or biodiversity losses are increasingly exposing the limits of the current linear “take, make, dispose” economy. On average, European Union (EU) residents consume the amount of natural resources as if there were three earths (WWF and Global Footprint Network, 2019). In addition, the extraction and refinement of natural resources account for 50 per cent of global greenhouse gas emissions and 90 per cent of biodiversity losses (International Resource Panel, 2019). In recent years, the circular economy (CE) concept has jumped to the forefront of policymaking, business and academia as a potential solution to these challenges. It aims to create economic and environmental benefits, by keeping products and materials at highest utility and value through long-lasting design, repair, reuse, refurbishment, and recycling (Ellen MacArthur Foundation, 2013; Geissdoerfer et al., 2017, 2018). In the European Union, the Circular Economy Action Plan is one of the main building blocks of the recent European Green Deal and COVID-19 recovery plan (European Commission, 2020). The UK passed a Circular Economy Policy Package (DEFRA UK, 2020), whilst in China, the Circular Economy Promotion Law came into effect in 2009 (McDowall et al., 2017).

At the individual firm level, the CE concept espouses that business models should change from selling products to providing functionality, through sharing, leasing or selling performance (Ellen MacArthur Foundation, 2013; Geissdoerfer et al., 2018; Lacy and Rutqvist, 2015). These types of business models in which products and services are combined to meet customer needs are called product-service systems (PSSs) (Tukker, 2004). Existing examples of PSSs are Rolls-Royces “Power-by-the-Hour” or Philips’ “Pay-per-Lux” offerings, in which the manufacturer is not paid according to the used products or service activities (e.g. repairs), but rather based on outcomes (e.g. the number of hours the engine is in the air or the amount of lighting used) (De Angelis, Howard and Miemczyk, 2018; Ng, Ding and Yip, 2013).

It is assumed that when manufacturers take over responsibility for product functionality or outcome, the product changes from being a consumable to a

capital asset (Hofmann, 2019; Tukker, 2015). Due to this change, manufacturers will profit from increasing resource efficiency and minimising product lifecycle costs (Hofmann, 2019; Tukker, 2015). As a result, the CE literature puts forward PSSs as critical elements in the transition from linear to circular supply chains (Ellen MacArthur Foundation, 2013; Lacy and Rutqvist, 2015; Lüdeke-Freund, Gold and Bocken, 2019; Yang et al., 2018). Circular supply chains slow, close, and narrow resource loops to increase competitive advantage as well as economic, environmental, and operational performance (Geissdoerfer et al., 2017, 2018). As such, supply chain circularity (SCC) is conceptualised as the extent to which supply chains are slow, closed, and narrow.

While the argument for PSSs' contribution to the transition to SCC is well established, it is predominantly based on conceptual and not empirical considerations (Tukker, 2004, 2015; Vezzoli et al., 2015). This presented an initial research opportunity to investigate the relationship between PSSs and SCC more closely. The outputs from the PhD research are presented in a paper format. Chapters 2 to 4 each provide a standalone paper drawn from my research. This chapter outlines the academic and personal research rationales, the research aim and objectives, as well as the research design and structure. The chapter concludes with an overview of how the findings have been disseminated so far.

1.1 Research rationale

This section explores the academic and personal rationale underlying this PhD thesis.

1.1.1 Academic rationale

This research is positioned at the intersection of the PSS, CE, and supply chain management (SCM) literature. The CE is an emerging concept with a wide variety of definitions in both academia and practice (Kirchherr, Reike and Hekkert, 2017). For the purpose of this study, a CE is defined as "a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing,

refurbishing, and recycling" (Geissdoerfer et al., 2017, p.766). It is aimed at absolutely decoupling economic growth from environmental impact (Hofmann, 2019; Kjaer et al., 2019).

Supply chains are a key unit of action in the transition to a CE (Ellen MacArthur Foundation, 2014). Integrating CE principles into supply chain management entails a transition from so-called linear to circular supply chains. In linear supply chains, resources are extracted from the planet, produced into products, used and then discarded at end-of-life (Farooque et al., 2019). Circular supply chains on the other hand, endeavour to minimise waste because they are designed to systematically restore and regenerate resources in the natural and business ecosystem in which they are embedded (Batista et al., 2018; Farooque et al., 2019). They cover the traditional forward supply chain as well as the reverse supply chain for product recovery activities, such as maintenance, repair, remanufacture, and recycle as well as useful by-products and other waste flows (Batista et al., 2018; Farooque et al., 2019). Circular supply chains slow, close, and narrow resource loops to increase competitive advantage as well as economic, environmental, and operational performance (Geissdoerfer et al., 2017, 2018).

The literature on PSSs is a strand of servitization-related research, which focuses on the transition of manufacturing firms from providing product-centric to service-centric business models (Rabetino et al., 2018). The PSS community is based on the transition from selling products to selling functionality to dematerialise the economy and reduce environmental impacts (Baines et al., 2009; Rabetino et al., 2018). The link between PSSs and CE can be traced back to Walter Stahel's concept of the performance economy (Stahel, 2010). This concept suggests moving away from product ownership and instead focusing on functionality, which provides opportunities for meeting customer needs with significantly less resources (Blomsma, 2018; Stahel, 2010). As such, both PSSs and CE are concepts that aim to contribute to industrial sustainability through productivity and innovation (Smart et al., 2017).

In the CE and PSS literature, there is an implicit assumption that PSSs contribute to SCC. By providing services instead of selling products, the role of products changes from consumable to capital asset (Hofmann, 2019; Tukker, 2015). Since products and consumables used to deliver the service become cost centres in these business models, it is assumed that manufacturers will maximise resource efficiency and optimise resource utilisation to increase their profitability (Hofmann, 2019; Stahel, 2013; Tukker, 2015). As a result, PSSs are expected to contribute to the slowing, closing, and narrowing of resource loops (Geissdoerfer et al., 2018; Hofmann, 2019; Lüdeke-Freund, Gold and Bocken, 2019).

According to the Ellen MacArthur Foundation (2013), PSSs' contribution to SCC presents a net material cost-saving opportunity of $520 billion to $630 billion a year in the EU in 2030. Nevertheless, manufacturers with PSSs may be reluctant to increase the SCC of its business models due to financial and operational risks stemming from internalising service activities and retaining product ownership (Ethirajan et al., 2021; Linder and Williander, 2017) or due to a lacking a sense of urgency (Kirchherr et al., 2018). At the outset of the PhD, the vast majority of papers investigating the relationship between PSSs and SCC were conceptual or theoretical and not empirical in nature (Reim, Parida and Örtqvist, 2015; Tukker, 2004, 2015; Vezzoli et al., 2015). This raised a crucial question: Are companies that offer PSSs really transforming how they do business or are they using SCC for marketing purposes and to mask linear 'business-as-usual'? Investigating this question is important, because it shows whether business models alone are an effective means to achieve SCC and create economic and environmental benefits or whether a more systemic change to the current socio-political system is needed for the desired CE transition.

The initial literature review exposed several pertinent gaps. Initial empirical evidence was primarily from start-ups that focused specifically on implementing PSSs based on CE principles (Corvellec and Stål, 2017; Manninen et al., 2018; Sousa-Zomer et al., 2018). There was only very limited empirical evidence from traditional manufacturing firms that pursued PSSs not for environmental but for strategic and commercial reasons (Yang et al., 2018). It was unclear whether

firms that are driven by strategic and commercial concerns would transition their supply chains towards circularity and how. Even though Matschewsky (2019) has since contributed initial case study evidence to this question, opportunities for further elaboration on the relationship between PSSs and SCC remain. In particular, there is an opportunity to contribute empirical evidence to a theoretical argument questioning the potential of PSSs to slow resource loops (Hofmann, 2019).

Moreover, there is a gap in regard to the role of contextual factors in a firm's transition to business models that increase SCC (Lüdeke-Freund, Gold and Bocken, 2019). Other empirical studies on the relationship between PSSs and SCC do not investigate these in more detail. Apart from a few exceptions (Vermunt et al., 2019), the literature on enablers and barriers for SCC do not focus specifically on PSSs, but on other types of business models associated with CE (Guldmann and Huulgaard, 2020; Tura et al., 2019). Hence, this thesis concentrates on investigating how PSSs relate to SCC and the role that contextual factors play in enabling and inhibiting this relationship.

1.1.2 Personal rationale

Before embarking on my PhD journey with the Marie Curie Circ€uit network, I previously studied BSc International Business Administration and MSc Industrial Ecology. In the MSc, I was first introduced to CE-related topics and got a first glimpse of academic research, by conducting a case study of industrial symbiosis development in the Dutch Province of Zeeland. Fuelled by the desire to become a CE expert and to hone my research and writing skills, I decided to pursue a PhD. The CE concept was fascinating to me, because it proposes a systemic overhaul to create cradle-to-cradle industrial metabolisms, instead of just trying to be 'less bad'.

The overarching purpose and objective of the Circ€uit network was to research and support the development of PSSs for a CE. This presented an excellent opportunity to learn more about how business model innovation could result in companies internalising the costs and risks of waste (Stahel, 2015).

When I commenced the PhD, PSSs were starting to emerge on the streets of my hometown Berlin, Germany, in the form of electric scooter- and bike-sharing schemes. While initially hailed as great steps in the transformation to a CE, it quickly became clear that PSS provider's fight for market share resulted in overcapacity and large amounts of waste. The potential drawbacks of unfettered PSS growth was best captured by the pictures of abandoned PSS bikes in China, which were circulated on social media in 2017 (see Figure 1-1). Clearly there was a misalignment between the current implementation of many PSSs and the narrative of resource use reduction espoused by the CE concept.

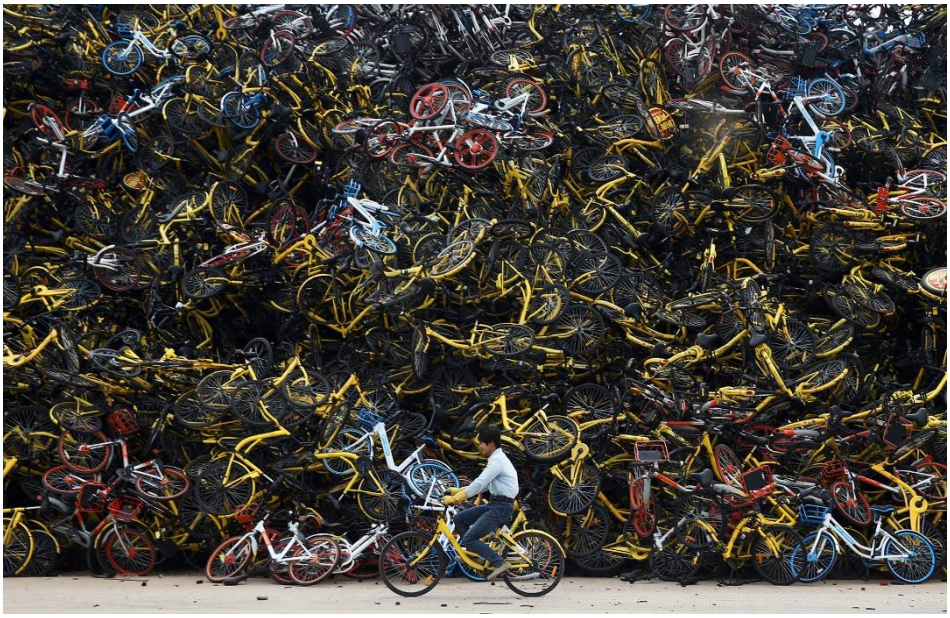

Figure 1-1 Discarded bikes from sharing schemes in China (Reuters, 2017)

As a result, I was motivated to understand more about how PSSs are implemented in practice and whether firms that provide PSSs re-align their business model to CE principles or whether they are a facade behind which linear 'business-as-usual' continues.

1.2 Research aims and objectives

This PhD thesis aims to contribute to the understanding of *how PSSs relate to SCC*, thereby examining the core of the CE's underlying business-driven approach (Geissdoerfer et al., 2017; Hofmann, 2019; Murray, Skene and Haynes, 2017). It aims to provide an empirical commentary on the potential ability for

business and innovation to create economic and environmental win-wins (Calisto Friant, Vermeulen and Salomone, 2020). This PhD thesis pursues three research objectives:

1) To systematically review the relevant literature to identify what is known about the relationship between PSSs and SCC and about the enabling and inhibiting effect that contextual factors have on this relationship;
2) To empirically investigate the relationship between PSSs and SCC;
3) To empirically investigate the enabling and inhibiting effect that contextual factors have on the relationship between PSSs and SCC.

Table 1-1 provides a summary of these objectives, the research method, the key findings associated with each objective and how they relate to the chapter structure. The thesis employs a mixed method approach, since it uses both qualitative and quantitative methods to collect and analyse data (Tashakkori and Creswell, 2007). Chapter 2 addresses the first research objective, whereas Chapters 3 and 4 both address the second and third research objectives.

Table 1-1 Thesis objectives, structure, method, and key findings

Chapter	Title	Description	
Chapter 1	Introduction	This chapter outlines the research rationale, research question (‘*How do PSSs relate to SCC?’)*, the research objectives as well as the research design and dissemination.	
Chapter 2 (Paper 1)	How does servitization affect supply chain circularity? – A systematic literature review	**Objectives:** to systematically review the relevant literature to identify what is known about the relationship between PSSs and SCC and about the enabling and inhibiting effect that contextual factors have on this relationship.	**Systematic literature review:** Evidence from 67 papers is synthesised into a conceptual map that explores the relationship between PSSs and SCC. It also identifies six contextual factors: economic attractiveness; firm sustainability strategy; policy and societal environment; product category; supply chain relationships; technology.
Chapter 3 (Paper 2)	Product-service systems and circular supply chain practices: The moderating effect of firm size and internal	**Objectives:** 1) To empirically investigate the relationship between PSSs and SCC, by investigating the impact of PSSs on SCC practice implementation;	**Survey:** A survey is conducted among 206 machinery and equipment manufacturing firms in the United Kingdom (UK). It shows that each PSS type uniquely contributes to the implementation of slowing,

Chapter	Title	Description	
	environmental orientation	2) To empirically investigate the enabling and inhibiting effect that contextual factors have on the relationship between PSSs and SCC, by analysing the moderating effects of internal environmental orientation and firm size.	closing, and narrowing practices. It finds internal environmental orientation and firm size do not moderate this relationship.
Chapter 4 (Paper 3)	Supply chain circularity implications of product-service systems: A multi-case study	**Objectives:** 1) To empirically investigate the relationship between PSSs and SCC; 2) To empirically investigate the enabling and inhibiting effect that contextual factors have on the relationship between PSSs and SCC.	**Multiple case studies:** Evidence from three case studies of machinery and equipment manufacturing firms in Germany and the UK. It shows that PSSs do not necessarily increase SCC and that the contribution depends on the effect of enablers or barriers in the contextual environment. Develops an empirically informed framework of contextual factors affecting the contribution of PSSs to SCC.
Chapter 5 (Paper 4)	Conclusion	This chapter sets out the theoretical and practical contributions of work. The limitations of the research are discussed and future research directions are proposed.	

1.3 Philosophical paradigm

This mixed methods PhD research is underpinned by a pragmatic approach, which seeks to transcend the two extremes of qualitative (social constructionism) and quantitative research (positivism) (Morgan, 2007). The choice for a mixed methods approach was motivated by two reasons. Firstly, the ability to offset the strengths and weaknesses of qualitative and quantitative research approaches by using both approaches (Plano Clark and Ivankova, 2017). Secondly, the chance to draw more valid conclusions about a phenomenon by triangulating the results obtained through both qualitative and quantitative approaches (Plano Clark and Ivankova, 2017). The philosophical underpinnings of this pragmatic mixed methods approach are explained in more detail in Table 1-2.

Table 1-2 Pragmatic approach to address methodological issues in social science research (Morgan, 2007)

	Qualitative Approach (i.e. Social constructionism)	**Quantitative Approach** (i.e. Positivism)	**Pragmatic Approach**
Connection of theory and data	Induction	Deduction	Abduction
Relationship to research process	Subjectivity	Objectivity	Intersubjectivity
Inference from data	Context	Generality	Transferability

The columns in Table 1-2 represent the main paradigms and the rows summarise the main implications and choices that are associated with each paradigm. According to the quantitative approach, the world exists externally and should be measured through objective methods (Easterby-Smith, Thorpe and Jackson, 2012). The qualitative approach on the other hand sees that reality is constructed by people instead of objective and external factors (Easterby-Smith, Thorpe and Jackson, 2012).

At first glance, this PhD research appears to be closer towards a quantitative approach, since it primarily relies on deduction for both the survey and the case study. Deductive theory testing is typically associated with a positivist approach in scientific research (Bitektine, 2008; Yin, 2018). Theory testing qualitative case studies can provide a valuable perspective on theories in settings when phenomena are unique, lack sufficient measures or are not as meaningful from a purely quantitative perspective (Bitektine, 2008; Yin, 2018). Nevertheless, the inductive analysis of contextual factors in the case study, ultimately positions this PhD research as abductive. The analysis of contextual factors, while guided by *a priori* considerations, emerged through a process of induction (Ketokivi and Choi, 2014). For example, the role of internal environmental orientation as an enabler first emerged in the SLR, but its specific effect on refurbishment in use-oriented PSSs emerged inductively in the case study. This back and forth process between induction and deduction is the essence of abduction in the pragmatic approach (Morgan, 2007).

The pragmatic approach does not propose an objective or subjective, but rather an inter-subjective relationship to the research process. This focuses on achieving sufficient mutual understanding with participants and readers of research outputs (Morgan, 2007). While the PhD research included objective elements, such as product lifetimes or recyclability and refurbishment rates, it also included subjective aspects, such as personal opinions. In terms of the case study, these subjective aspects were particularly critical to understanding the how and why behind the objective data. The same applies to the survey, which uses statistical methods to allow for a broad comparison of a large population, but ultimately still relies on respondent's personal and thus subjective opinions.

My role as a researcher embodies the pragmatic emphasis on intersubjectivity, by acknowledging the duality of being both objective and subjective. It is subjective, because it is sparked by a personal interest in the role of businesses as change agents for the transition to a CE sparked my interest in the topic. On the other hand, it also seeks objectivity, for example, by choosing a case study methodology according to Yin (2018), which emphasises structure, rigour, and triangulation of information.

The final aspect is the inference from data. The qualitative paradigm typically focuses on knowledge that is specific and context-dependent, whereas the quantitative paradigm makes universal or generalised claims (Morgan, 2007). The pragmatic approach tries to overcome these two extremes. Transferability helps to establish which set of circumstances might enable existing knowledge to be usable. In the survey, a sense of generality is developed by the number of respondents in the sample. The case study helps contextualise the results of the survey. Its contradiction of the deduced hypotheses as well as the exploration of contextual factors helped refine the understanding as to what contexts the theory lends itself (Tsang, 2014). Overall, the pragmatic philosophical stance makes it possible to work back and forth between the qualitative and quantitative extremes and to ultimately benefit from both approaches to social science research.

1.4 Research design and structure

This mixed methods PhD uses both qualitative and quantitative research approaches to investigate the phenomenon of the relationship between PSSs and SCC (Tashakkori and Creswell, 2007). Figure 1-2 provides a graphical representation of the research process.

This thesis is organised in paper format. This means that it is structured to deliver its contributions through three separate chapters, each in the style of a journal article. At the time of writing this thesis, the papers are all at different stages in the publication process. In summary, these chapters describe a single piece of research contributing to the overall aim of the thesis.

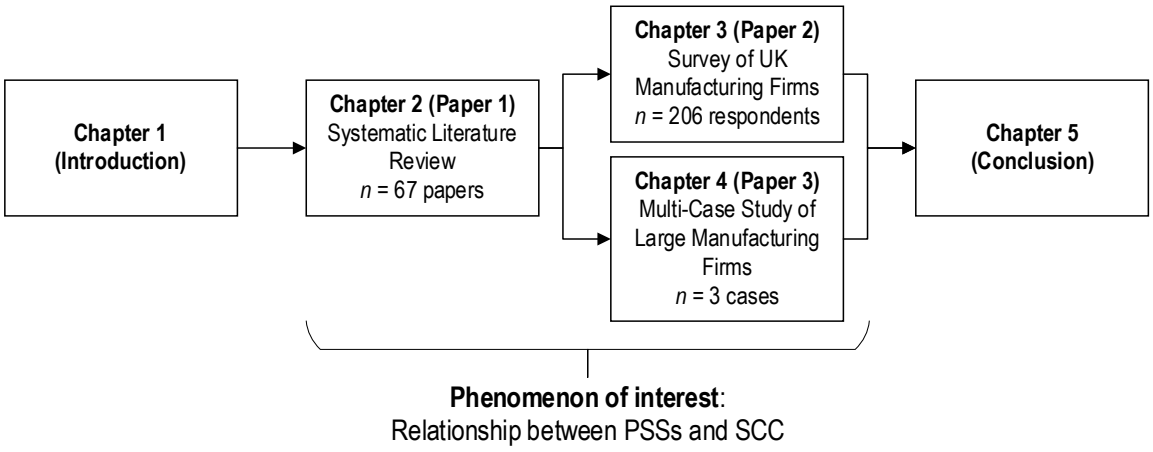

Figure 1-2 Overview of research design

This PhD thesis is based on a concurrent or complementary mixed methods research design (Creswell and Plano Clark, 2018; Plano Clark and Ivankova, 2017). In this approach, qualitative and quantitative research approaches are conducted concurrently with the purpose of producing a more complete and comprehensive understanding of the phenomenon under study (Plano Clark and Ivankova, 2017). This type of approach seeks to enhance, elaborate, illustrate or clarify the results from one method with those of another method (Creswell and Plano Clark, 2018; Varga, 2018). All three papers in this thesis (Chapters 2-4) investigate the same phenomenon, namely the relationship between PSSs and SCC, albeit from different perspectives.

In this thesis, the three papers are framed by the introduction (Chapter 1) and the conclusion (Chapter 5). Chapter 1 positions the research within the wider academic literature, and explains the research structure and design. Chapter 5 synthesises the findings from the three papers (Chapters 2-4) together and discusses the theoretical contributions, practical implications, limitations as well as the opportunities for further research.

1.4.1 Chapter 2: Laying the conceptual foundations

Chapter 2 provides the conceptual foundation for both empirical papers, by deducing an initial conceptual map and a list of propositions from the literature. It adopts a systematic literature review (SLR) method (Tranfield, Denyer and Smart, 2003) to select, map, and assess existing studies on CE and PSS. This method is chosen, because compared to a critical literature review, a SLR provides a more rigorous and transparent review process that allows for explanatory or interpretive findings (Denyer and Tranfield, 2009). The study identifies 67 studies and synthesised them using content analysis. It addresses the first research objective of the thesis: To systematically review the relevant literature to identify what is known about the relationship between PSSs and SCC and about the enabling and inhibiting effect that contextual factors have on this relationship.

In regard to the relationship between PSSs and SCC, the SLR deduces a conceptual map and puts forward research propositions. These suggest that SCC is highest in result-oriented PSSs, followed by use-oriented PSSs and finally product-oriented PSSs. The conceptual map and research propositions are subsequently tested in both empirical papers.

In regard to the role of the contextual factors, the SLR identifies and groups them into six categories: 1) Economic attractiveness of supply chain circularity; 2) Firm sustainability strategy; 3) Policy and societal environment; 4) Product category; 5) Supply chain relationships; 6) Technology. In particular, the review highlights the role of firm sustainability strategy in enabling the contribution of PSSs to SCC. This part of the conceptual map was also tested in both empirical papers. In Chapter 3, two contextual factors are introduced in the form of moderating variables: internal environmental orientation as well as firm size.

Moreover, Chapter 2 lays the foundation for the thesis' contribution to the development of the SCC concept. Specifically, it identifies 15 practices as well as measures for assessing SCC. Chapter 3 further refines this work to develop a set of empirically validated measurement items for SCC practices.

Finally, while not directly addressed in Chapter 2, the choice of theory is another important conceptual foundation for this PhD thesis. Chapters 3 and 4 both use the natural resource-based view (NRBV) (Hart, 1995) as a theoretical lens to deduce the underlying hypotheses. The theory is based on the resource-based view (RBV), which suggests that a firm is able to derive competitive advantage from its resources and capabilities (Barney, 1991). Hart (1995) argued that the RBV did not consider the relationship between the natural environment and the firm for sustained competitive advantage. His NRBV postulates that future competitive advantage is rooted in "capabilities that facilitate environmentally sustainable economic activity" (Hart, 1995, p.991). There were three reasons for choosing the NRBV: 1) it reflects CE's business-driven and green growth approach, by suggesting that firms can create economic and environmental win-win outcomes through innovation; 2) it explains why result-oriented PSSs have the highest potential contribution to SCC, followed by use-oriented and finally product-oriented PSSs, namely due to increasing manufacturer-customer integration; 3) its scope focuses on activities, such as reverse logistics or closed-loop supply chains, which are conceptually related to SCC (Batista et al., 2018).

1.4.2 Chapter 3: The quantitative empirical research element

Chapter 3 provides the quantitative element to this mixed methods investigation. It tests a conceptual framework rooted in the findings of Chapter 2, which contributes to the second and third research objectives. It does so, by conducting a survey among 206 machinery and equipment manufacturing firms in the United Kingdom (UK). The focus on machinery and equipment manufacturing firms was motivated by the fact that PSSs are most prevalent in these industries (Baines and Shi, 2015; Luoto, Brax and Kohtamäki, 2017).

Chapter 3 contributes to the second research objective, by testing hypotheses on the contribution of PSSs to the implementation of SCC practices: practices

associated with the slowing, closing, and narrowing of resource loops. This link was first suggested in Chapter 2. The survey also contributes to the third research objective, by including two moderating variables that were adapted from the initial list of contextual factors in Chapter 2: internal environmental orientation and firm size.

Internal environmental orientation refers to managers' and employees' values and ethical standards in regard to environmental protection (Banerjee, 2002). It can be conceptualised as a pro-environmental culture that manifests itself in a firm's mission statements, policies, procedures, and the training of employees (Banerjee, 2002; Chan et al., 2012). This construct was chosen as a proxy for firm sustainability strategy: a contextual factor deduced in Chapter 2 and considered to be an important enabler in the relationship between PSSs and SCC. There were two reasons for adopting this construct: 1) It covered the identified aspects of firm sustainability strategy; 2) there were previously existing reliable and valid measurement scales and items.

The second moderating variable included in the survey was firm size. Although not directly identified as a stand-alone category of contextual factors, it was indirectly included in the category on the 'economic attractiveness of SCC'. Specifically, it was suggested that the cost impact could have a negative effect on the relationship between PSSs and SCC, "by increasing operational, planning, and/or sourcing costs" (Kühl et al., 2019, p. 718). To examine the potentially negative effect of the cost impact, firm size was chosen as a moderating variable. Compared to large firms, smaller firms may not have the resources to implement SCC practices (Rizos et al., 2016).

Chapter 3 provides the first survey-based empirical investigation of the relationship between PSSs and SCC practice implementation. To date, the use of quantitative research methods, such as surveys, are particularly underutilised in the PSS domain (Rabetino et al., 2018) and just starting to emerge in the CE literature (Gusmerotti et al., 2019; Kumar et al., 2019; Liakos et al., 2019). Partial Least Squares structural equation modelling (PLS-SEM) was conducted to evaluate the model. This study shows that product-oriented PSSs leads to the

implementation of practices associated with the slowing of resource loops, use-oriented leads to the implementation of practices associated with the closing and result-oriented leads to the implementation of practices associated with the slowing, closing and narrowing of resource loops. It finds that firm size and internal environmental orientation do not moderate this relationship. The developed measurement items can assist manufacturers in benchmarking the implementation of SCC practices.

1.4.3 Chapter 4: The qualitative empirical research element

Chapter 4 is the qualitative element of the empirical research and complements Chapter 3, by providing a more context-specific examination of the relationship between PSSs and SCC. It conducts a theory-testing case study, which is also comprised of inductive elements regarding the effect of contextual factors (Ketokivi and Choi, 2014).

Chapter 4 contributes to the second research objective, by testing deduced hypotheses regarding the increasing contribution of use- and result-oriented PSSs compared to product-oriented PSSs. The qualitative case study nature makes it possible to directly compare the SCC implications of different PSSs. Contrary to Chapters 2 and 3, however, the examination of SCC focuses solely on the slowing and closing of resource loops – and not the narrowing. This decision is motivated by the fact that slowing and closing are considered the most critical modes of value creation for SCC (Hofmann, 2019; Lüdeke-Freund, Gold and Bocken, 2019). The analysis is enabled by the slowing and closing metrics developed by Figge et al. (2018).

Chapter 4 contributes to the third research objective, by exploring the role of contextual factors. This represents the inductive element of the predominantly deductive theory-testing case study (Ketokivi and Choi, 2014). In the literature review section of Chapter 4, a framework of contextual factors is presented that differs from the one presented in Chapter 2. This new framework emerged from an updated literature search conducted after the publication of the SLR. The categories were based on newly identified papers (Tura et al., 2019; Vermunt et al., 2019) that classified contextual factors along internal and external dimensions

and distinguished between the following categories: 1) Organisational; 2) Financial; 3) Technology and Knowledge; 4) Market; 5) Supply chain; 6) Regulatory. There were three main reasons for adopting these categories.

Firstly, the categories are worded more comprehensively. While highlighting the role of specific contextual factors, the original categories were formulated in a way that excluded the potential impact of other factors. For example, the formulation of 'firm sustainability strategy' would potentially exclude the role of other organisational factors. In addition, the wording of 'economic attractiveness of SCC' could not conceptually include the role of a firm's access to capital (Rizos et al., 2016), whereas a broader 'financial' category could.

Secondly, they facilitated the categorisation of contextual factors. For example, the framework from Chapter 2 included a barrier in the 'product category' around products not being designed for SCC. Nevertheless, whether a product design is suitable for SCC practices, such as maintenance or refurbishment, is closely related to the use of digital technologies in a product and which could have therefore also been included in the 'digital technology' category (Alcayaga, Wiener and Hansen, 2019). In the new framework, aspects around product designs and technology were combined into one 'technology and knowledge' category. Compared to the original framework from Chapter 2, this updated framework facilitated the analysis. Thirdly, the categories were conceptually close enough, which made it possible to include the same enablers and inhibitors identified in Chapter 2.

The multiple-case studies were conducted in three large machinery and equipment manufacturing firms in the UK and Germany. They provide different PSS types for personal computers, power tools, and wind turbines. The case studies were purposively sampled from large multinational corporations to enable a comparison of SCC contributions of product-oriented PSSs with use-oriented and result-oriented PSSs. This is justified by the fact that In Europe, complex PSSs, such as use-oriented or result-oriented PSSs are predominantly offered by large firms (Poel et al., 2018).

Diversity among the case studies was sought based on the speed of product innovation cycles in an industry. There were three key reasons for choosing this case study diversity dimension. Firstly, it was identified as a contextual factor in the SLR. Specifically, Chapter 2 suggests that product characteristics can inhibit the relationship between PSSs and SCC, through aesthetic, functional or economic deterioration over time. Hence, products will become obsolete more quickly in industries with a greater speed of product innovation cycles, which in turn would limit opportunities for PSSs to contribute to a slowing of resource loops. Secondly, this dimension addressed a key theoretical concern around PSSs, namely whether they are suitable for overcoming consumerist approaches in the economy (e.g. fast fashion or fast electronics) (Hofmann, 2019; Merli, Preziosi and Acampora, 2018). Thirdly, this dimension was easily quantifiable and provided a clear and unambiguous measure, which facilitated the case selection process.

Multiple sources of evidence were triangulated to improve construct validity, including 19 semi-structured interviews, company documents, and quantitative data. The research shows that in comparison to product-oriented PSSs, use-oriented and result-oriented PSSs do not necessarily contribute to the slowing and closing of resource loops. It provides empirical evidence for nineteen enablers and barriers and how they affect the contribution of different PSS types to the slowing and closing of resource loops. This paper makes three key contributions: Firstly, it shows that the contribution of PSSs is not only dependent on the PSS type, but also on the presence of enablers and barriers in the firm context. Secondly, it induces four propositions that highlight the enabling and inhibiting effect of contextual factors, in particular of organisational factors on the contribution of use-oriented PSSs to the slowing of resource loops through refurbishment. Thirdly, it develops an empirically validated conceptual framework that accounts for the effect of enablers and barriers on the contribution of the different PSSs on the slowing and closing of resource loops.

1.5 Research dissemination

Table 1-3 represents a summary of all research dissemination of the papers.

Table 1-3 Research dissemination

Papers	Journal paper	Conference papers / practitioner presentations
Paper 1 (Chapter 2)	**Published:** Kühl, C., Bourlakis, M., Aktas, E. and Skipworth, H. (2019), "How does servitisation affect supply chain circularity? – A systematic literature review", *Journal of Enterprise Information Management*, Vol. 33 No. 4, pp. 703–728.	Kühl, C., Tjahjono, B., Bourlakis, M. and Aktas, E. (2018), "Implementation of Circular Economy principles in PSS operations", *Procedia CIRP*, , Vol. 73, pp. 124–129.
Paper 2 (Chapter 3)	**Under review:** Kühl, C., Bourlakis, M., Aktas, E. and Skipworth, H. (2021), "Product-service systems and circular supply chain practices: The moderating effect of internal environmental orientation", *Journal of Business Research*	
Paper 3 (Chapter 4)	**In preparation:** Kühl, C., Bourlakis, M., Skipworth, H. and Aktas, E. (2021), "Supply chain circularity implications of product-service systems: A multi-case study", *International Journal of Operations & Production Management / International Journal of Production Research*	"Circular business models: An introduction and case study" presented to business practitioners at Academy for Circular Economy, Belgrade, Serbia, November 2019

As the lead author on these three papers, I proposed the overall topic of the thesis as well as the scope and objectives of each paper. My supervisors supported me in the refinement of the research as well as the execution. They are also the co-authors of my papers. I designed the research method and conducted data collection as well as analysis, with the support of my supervisors. Prof Michael Bourlakis and Prof Emel Aktas were particularly supportive in the design of the systematic literature review and the survey paper, whereas Dr Heather Skipworth was especially instrumental in the design of the case study. I fully drafted the three papers with the feedback of my supervisors.

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2 How does servitization affect supply chain circularity? - A systematic literature review (Paper 1)

Abstract

The aim of this SLR is to test the link between servitization and circular economy (CE), by synthesising the relationship between product-service systems (PSSs) and supply chain circularity (SCC). Following a systematic literature review (SLR), the study identified 67 studies and synthesised them using content analysis. It extends the SCC concept, by linking the three modes of slowing, closing, and narrowing to fifteen practices from materials sourcing to recovery as well as identifying outcome measures for each SCC mode. Based on a review of empirical evidence of PSS implementation, a conceptual map is established that posits that the slowing, closing, and narrowing of resource loops is highest in result-oriented PSSs, followed by use-oriented and finally product-oriented PSSs. It proposes that the main contribution stems from an increased slowing of resource loops, followed by closing, and finally narrowing resource loops. Moreover, the model also identifies and categorises six contextual factors affecting the relationship between PSSs and SCC including: 1) Economic attractiveness of SCC; 2) Firm sustainability strategy; 3) Policy and societal environment; 4) Product category; 5) Supply chain relationships; 6) Technology. The model is deduced from the literature by using secondary data. The review provides practitioners with a framework to increase SCC through PSSs. It also identifies and categorises the various contextual factors that may affect how PSSs contribute to SCC. This review contributes by systematically synthesising knowledge on the relationship between PSSs and SCC and by identifying a range of contextual factors that affect this relationship.

Keywords Supply chain management, systematic literature review, circular economy, servitization, product-service system

2.1 Introduction

The circular economy (CE) concept advocates that business models should change from selling to renting, leasing, or sharing technical products (Ellen MacArthur Foundation, 2013; Lacy and Rutqvist, 2015). These business models are considered a key enabler to the development of circular supply chains (De Angelis, Howard and Miemczyk, 2018; Batista et al., 2018; Ellen MacArthur Foundation, 2013; Lacy and Rutqvist, 2015). A CE is defined as “a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling” (Geissdoerfer et al., 2017, p.766). Supply chains are a key unit of action in the transition to a CE (Ellen MacArthur Foundation, 2014). Circular supply chains slow, close, and narrow resource loops to increase competitive advantage as well as economic, environmental, and operational performance (Geissdoerfer et al., 2017, 2018).

The interest in manufacturers moving away from selling products to providing combinations of goods and services emerged in the late 1980s (Vandermerwe and Rada, 1988; Wise and Baumgartner, 1999). The so-called servitization phenomenon was a response to competitive pressures, as manufacturers sought differentiation opportunities by offering services along the entire product lifecycle (Oliva and Kallenberg, 2003). The most well-known example is the Rolls-Royce’s ‘Power-by-the-Hour’ scheme. Instead of selling jet engines, Rolls-Royce carries out installation, maintenance, repair, and modernisation services while charging customers only for using the engine (Ng, Ding and Yip, 2013). Even though most servitization cases stem from business-to-business contexts, examples also emerge from consumer markets, such as car-, bike- or washing machine-sharing (Geissdoerfer et al., 2018; Manninen et al., 2018).

Servitized offerings are often referred to as product-service systems (PSSs). These PSSs are defined as “tangible products and intangible services designed and combined so that they jointly are capable of fulfilling specific customer needs” (Tukker, 2004, p.246). Other terms to describe such offerings are basic,

intermediate, or advanced services (Baines and Lightfoot, 2013), outcome-based contracts (Ng, Maull and Yip, 2009), performance-based contracts (Hypko, Tilebein and Gleich, 2010), or industrial solutions (Brady, Davies and Gann, 2005). PSSs are usually typified along a product-service continuum, in which the focus of the offering changes from being mainly product-based towards being more service-based (Tukker, 2004). There are three main PSS categories:

- *Product-oriented*: The main focus is still on selling products. The offering is enhanced by product-related services, such as maintenance or insurance contracts (Gaiardelli et al., 2014; Tukker, 2004).
- *Use-oriented*: The focus is on providing functionality or access, for example, through leasing, renting, or sharing instead of selling products (Gaiardelli et al., 2014; Tukker, 2004).
- *Result-oriented:* In these services, a function or pre-determined result is provided and not a specific product (e.g. pay-per-unit). The provider is free to decide how results are delivered (Gaiardelli et al., 2014; Tukker, 2004).

To date, the link between PSSs and SCC is mainly theoretical. It is based on the assumption that when companies provide services instead of selling products, they are incentivised to optimise their resource utilisation, for example by improving efficiency, increasing product lifetime, or reducing the overall number of products in use (Reim, Parida and Örtqvist, 2015; Tukker, 2004; Vezzoli et al., 2015). Use- and result-oriented PSSs are considered to have the highest SCC potential because the manufacturer retains product ownership and thereby responsibility over the product lifecycle (Reim, Parida and Örtqvist, 2015). As a result, the manufacturer has economic incentives to reduce the costs for service delivery as well as to recover value at end-of-life, for example through reuse or remanufacturing (Vezzoli et al., 2015).

Increasing supply chain circularity (SCC) has been shown to reduce costs and generate new revenue streams. In 2017, Hewlett Packard refurbished and remarketed 1.27 million units of hardware, thereby creating new sales opportunities (Strandberg, 2017). JLG industries, a manufacturer of material handling equipment, reduced its equipment costs by 35% by refurbishing old

cherry pickers (Ellen MacArthur Foundation, 2017a). Through remanufacturing, Caterpillar is able to get the same performance of components at 50-60% of the cost (Ellen MacArthur Foundation, 2017b). Even though the case for increased net value creation from SCC is clear, manufacturers may be reluctant to implement PSSs due to business risks associated with product ownership retention (Linder and Williander, 2017). Moreover, it is questionable how important the environmental concerns for PSS providers are, since servitization is predominantly driven by strategic and commercial interests (Baines et al., 2009a; Oliva and Kallenberg, 2003). As a result, selling PSS instead of products may not always lead to higher circularity (Kjaer et al., 2019; Tukker, 2004).

The aim of this review is to test the assumed link between servitization and CE by synthesising the relationship between PSSs and SCC. It aims to answer three review questions:

1) What is SCC?
2) How do PSSs affect SCC?
3) What contextual factors affect the relationship between PSSs and SCC?

The paper adopts a systematic literature review (SLR) methodology to identify and review 67 articles from the CE and PSS/servitization fields. This review presents the first attempt to bridge the gap between theory and practice of SCC, by reviewing only empirical cases of PSSs implementation. This helps validate the theoretical claims made about this relationship (Tukker, 2004). It provides new knowledge by identifying and synthesising the contextual factors that can affect SCC implementation in PSSs. The practical rationale for the study stems from the observation that the business case for adopting SCC in practice is not always as straightforward as suggested by the literature (Linder and Williander, 2017).

2.2 Research method

This study adopts a systematic review process to select, map, and assess existing studies on CE and PSS (Tranfield, Denyer and Smart, 2003). Compared to a critical literature review, a SLR provides a more rigorous and transparent

review process that allows for explanatory or interpretive findings (Denyer and Tranfield, 2009). Using such an approach can reduce bias and increase the legitimacy of the data analysis, thereby leading to more reliable results (Becheikh, Landry and Amara, 2006). To ensure the transparency and replicability of this study, a series of steps were followed (Denyer and Tranfield, 2009) and presented in a similar way to Pilbeam et al. (2012): 1) planning, 2) searching, 3) screening, 4) extraction and synthesis, and 5) reporting. The search and selection processes are summarised in Figure 2-1 (Pilbeam et al., 2012).

Planning

In advance to this study, the authors carried out a scoping study as suggested by Tranfield et al. (2003). Based on these results, the research team and a guidance committee consisting of other academic experts in the field defined the research scope, questions, and inclusion/exclusion criteria to answer the aforementioned review questions.

Searching

Table 2-1 Search Strings

SS1: Supply Chain Management		**SS2: Circular Economy**		**SS3: Product-service systems**
Supply Chain*		Circular Economy		Product?service?system
Value Chain*				PSS
Demand Chain*				Serviti?ation
Logistics	**AND**		**AND**	Outcome?based
Supply Network*				Advanced services
Value Network*				Industrial service
Operations*				Hybrid solution
				Functional sales
				Performance?based

The keywords used in the literature search emerged from the scoping study (see Table 2-1). For the CE category only one keyword was used. In addition to the CE concept, this term could have included related supply chain narratives, such

as closed-loop supply chains, green, or sustainably supply chains. Even though they are related to the CE concept, they extend these concepts since CE takes into account cascading flows into different supply chains (Batista et al., 2018). Since CE is related to these narratives, but still different, a decision was made to focus only on the CE concept.

The keywords were classified into search strings by using Boolean 'OR' operators, namely, supply chain management, CE, and PSS. To answer the first question ('What is SCC?'), SS1 and SS2 were combined through a Boolean 'AND' operator. The second question ('How do PSS business models affect SCC?') and the third question ('What contextual factors affect the implementation of SCC?'), were answered by combining all three strings. These search strings were then used to search two bibliographic (Scopus and Web of Science) and two content-based databases (ABI/Proquest and Ebsco). A total of 3,034 articles were identified and alerts were set up in the databases to help identify new publications.

Screening

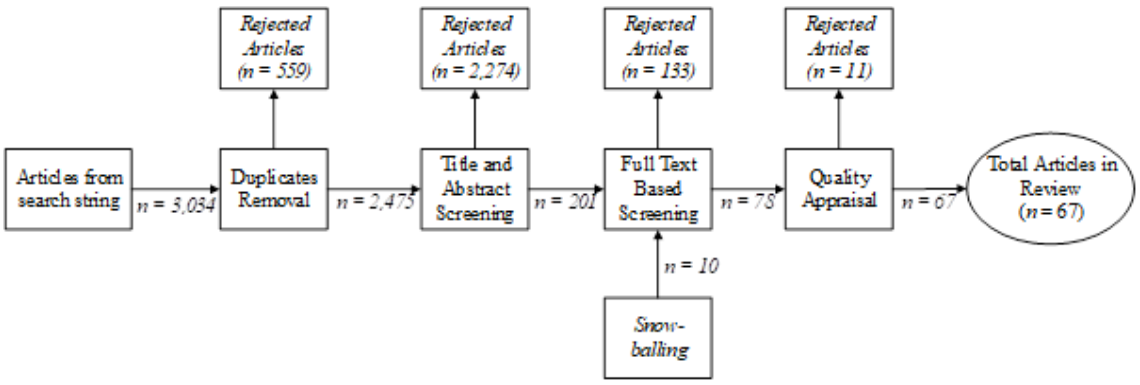

Figure 2-1 Paper search and selection process

The paper selection process is described in Figure 2-1. 3,034 search results were exported from Scopus, Web of Science, ABI/Proquest and Ebsco to the reference management software Mendeley. Table 2-2 provides a detailed overview of the search results across the four databases.

Table 2-2 Search results across the four databases

	SS1 + SS2	SS1+ SS3	SS1+2+3
Scopus	262	898	240
Ebsco	359	219	4
ABI	297	258	1
WoS	272	223	1

Following the removal of 559 duplicates, 2,475 articles remained. The first screen of the articles was based on the article title and abstract against pre-determined inclusion (and exclusion) criteria (see Table 2-3).

Table 2-3 Criteria for including papers in the review

Criteria	**Rationale**
Published in peer-reviewed journals	Peer-reviewed journal articles are likely to have a higher quality than non-peer reviewed publications, such as conference papers or reports.
Studies that are written in English	Language skills of the authors.
Open to any time frame	The field developed significantly since the 1980s, but some seminal papers predate this.
Open to any geography	Contributions to the research area stem from around the world.
Theoretical, empirical studies and review papers, either qualitative or quantitative	Different methodological approaches contribute to the research domain.
Focused on ('supply chain management' AND 'circular economy') OR ('supply chain management' AND 'product-service systems') OR ('supply chain management' AND 'circular economy' AND 'product-service systems')	Different search string combinations are required to answer the review questions.

After rejecting 2,274 articles, 201 articles remained, which were then reviewed in a rigorous full-text screening process against the same inclusion and exclusion criteria. During this screening process, the references of relevant articles were reviewed (snowballing) to identify other potentially relevant articles. The snowballing process identified an additional 10 papers. These additional papers

primarily belonged to the PSS and servitization-related literature. The relatively high amount of snowballed papers stems from the papers describing relevant practices and aspects, such as maintenance and repair, but not using any keywords related to operations or supply chain management.

Following the full-text screening, 78 articles remained. The selected articles were subject to a quality appraisal process that covered the theory robustness, methodology, findings, and contribution (Pittaway et al., 2004). The articles were scored on a scale of zero to three in each category. To be included, an article required a score of at least six in total. Eleven articles were rejected in this step leaving 67 articles, which qualify for review.

Extraction and synthesis

There are different approaches to data extraction and synthesis in SLRs. This review is based on heterogeneous qualitative and quantitative data. As a result, it is not suitable to use aggregative synthesis methods (Rousseau, Manning and Denyer, 2008). In addition, an integrative approach was also excluded, since the review questions do not focus on exploring when interventions are likely to be appropriate (Rousseau, Manning and Denyer, 2008). Instead, a mix of interpretive and explanatory approaches was used (Rousseau, Manning and Denyer, 2008). In these methods, descriptive data and exemplars are extracted from studies to create explanations (Denyer, Tranfield and van Aken, 2008). Content analysis is used as an extraction and synthesis method, since it can provide detailed assessments of descriptive and content criteria and also extend the perspective beyond single studies (Gold, Seuring and Beske, 2010; Seuring and Müller, 2008).

In the first step of content analysis, papers were classified based on descriptive dimensions. This included the distribution across time, the employed research methodology, geographic context, industry setting, PSS type, and the journal the paper was published in. These categories were selected based on the standard practice for literature reviews (Seuring and Müller, 2008), as well as the inclusion and exclusion criteria of the study. In addition, analytic categories for the supply chain processes and the contextual factors affecting SCC were developed from

the reviewed papers by means of generalisation (Seuring and Müller, 2008). One of the weaknesses of content analysis is that it relies on the researcher to judge how a paper is to be comprehended (Seuring and Müller, 2008). To account for this, the first author regularly discussed findings and coding matters with the other authors and resolved any disagreements through discussion. The dimensions and categories were iteratively revised during the analysis process.

2.3 Descriptive analysis

This section presents the descriptive analysis of the literature review. The papers were classified in three categories: CE, PSS and circular PSS, where both themes overlapped. The CE and circular PSS papers answered the first review question, all papers answered the second and third review question. Figure 2-2 depicts the distribution the 67 reviewed papers.

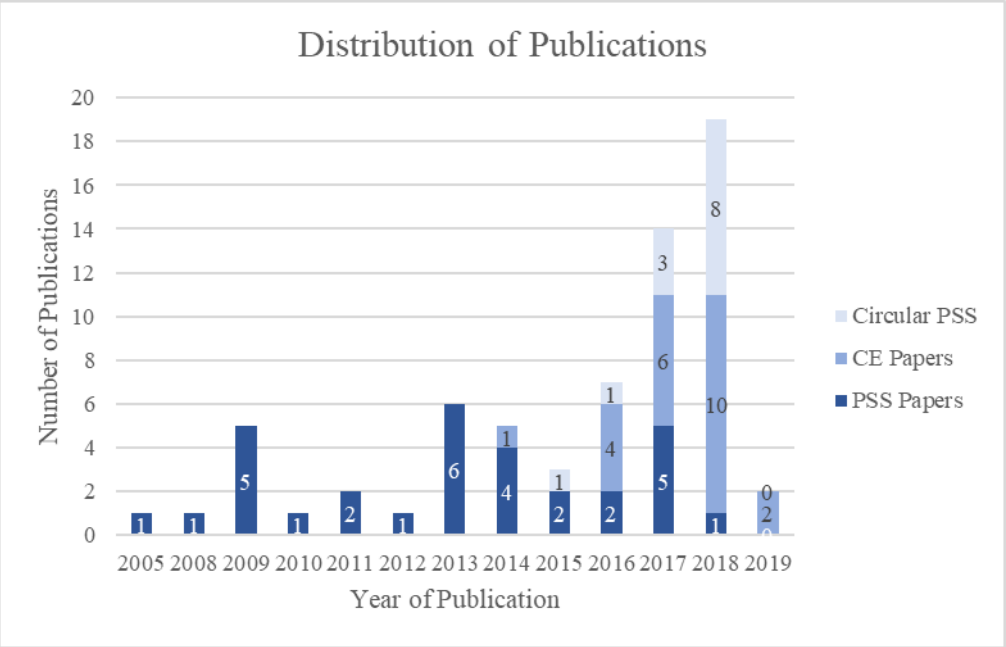

Figure 2-2 Distribution of publications

Figure 2-2 shows that between 2005 and 2013, the publications exclusively focused on PSS and servitization. In 2014, publications on CE slowly started to emerge, with the number of publications rising sharply between 2017-2018. Indeed, there was a particular increase in 2018 of those papers addressing both

CE and PSS. This shows that the link between the CE and the PSS/servitization literature emerged only very recently.

The selected papers were categorised and analysed in regard to methodology, geographic context, industry setting, PSS type and journal (see Table 2-4). The methodologies were categorised based on the study types provided by Habib, Bastl and Pilbeam (2015). The selected articles were divided across non-empirical papers (21) and empirical papers (46). In the non-empirical papers, the dominant type were literature reviews (12) and conceptual papers (8), while one was classified as mathematical. The majority of these papers focused on CE and circular supply chains (De Angelis, Howard and Miemczyk, 2018; Batista et al., 2018). The empirical papers were predominantly case studies (42) compared to four papers based on surveys. Of the case studies, 39 focused on PSS of which 9 focused more specifically on circular PSS implementation. The dominance of case study methodologies underscores that this research area is in a nascent stage and still exploring the manifestation of this phenomenon in its real-life context.

Table 2-4 Descriptive analysis of the literature review

Descriptive Category	*Sub-Category*	*Number of Papers*
Research Methodology	*Non-Empirical*	
	Conceptual	8
	Literature Review	12
	Mathematical	1
	Empirical	
	Case studies	42
	Survey	4
Geographic Context*	None	21
	Asia	2
	Australia	1
	Europe	40
	North America	1
	South America	3
	Worldwide	1
Industry setting*	Aerospace	2
	Automotive	3
	Bicycles	2
	Capital equipment	14
	Chemical/food	1

Descriptive Category	*Sub-Category*	*Number of Papers*
	Construction equipment	4
	Defence	6
	Household appliances	6
	Material handling equipment	3
	Medical equipment	3
	Office equipment	1
	Textiles	3
	Transportation equipment	3
PSS Type*	Product-Oriented	14
	Use-Oriented	12
	Result-Oriented	24
Journal**	Journal of Cleaner Production	15
	International Journal of Operations & Production Management	9
	International Journal of Production Economics	5
	Industrial Marketing Management	5
	Production Planning & Control	5
	Sustainability	5

*May vary since some papers employed multiple case studies.
**Includes top six most frequently included journals

The non-empirical papers were not classified according to geographic context, since they did not provide any specifications in this category. Almost all empirical papers focused on cases from European countries (40), especially from the United Kingdom (17) or Sweden (7), and only few exceptions from other contexts, such as Brazil (3) or China (1). The empirical papers were mainly from industries related to manufacturing, such as capital equipment, defence, or household appliances. Nevertheless, a growing number of publications focused on lower value product industries, such as textiles (Corvellec and Stål, 2017; Pal, 2016). The 39 empirical PSS papers were differentiated based on the type of PSS. This total number exceeds 39 since some papers employed multiple case studies of different PSS types. There were 14 cases of product-oriented PSS, 12 cases of use-oriented PSS and 24 cases of result-oriented PSS indicating the high level of interest that PSS/ servitization scholars have in these. The analysis reveals that the discussion around supply chain and CE has primarily taken place in journals, such as the Journal of Cleaner Production, Production Planning &

Control, or Sustainability. The PSS and servitization literature, however, is focused primarily on the International Journal of Operations & Production Management, Industrial Marketing Management and the International Journal of Production Economics.

2.4 Thematic analysis

This section presents the thematic findings of the review. In the first part, the CE literature was reviewed to identify relevant SCC modes, indicators, and practices. In the second part, empirical PSS papers were reviewed to identify SCC practices. In the final part of this analysis, contextual factors for the implementation of SCC were deduced from the CE and PSS literature. The main purpose of the review is to develop a conceptual map of SCC in PSSs. The final framework is presented in Figure 2-3.

2.4.1 SCC

This section focuses on identifying relevant SCC mode, performance measures, and practices (see Table 2-5).

Table 2-5 SCC mode, practices and performance measures

SCC mode	Associated Practices	Performance Measure	Performance Measure Source
Slow resource loops	Design for disassembly; Design for longevity; Design for modularity; Reuse/Resell; Maintenance and Repair; Refurbish	Longevity = A + B + C A is initial life time of the product; B is refurbished lifetime contribution; C is recycled lifetime contribution.	Franklin-Johnson, Figge and Canning (2016)
Close resource loops	Source secondary materials; Cascading; Recycling; Remanufacturing	Circularity = (economic value of recirculated parts) / (economic value of all parts)	Linder, Sarasini and van Loon (2017)
Narrow resource loops	Source secondary materials; Customisation; Reduce resource use; Eco-efficient production processes / technology;	Decreasing emissions (e.g. GHG emissions; Air) Decreasing energy consumption (e.g. Energy consumption; use of renewable energy sources)	Genovese et al. (2017); Kazancoglu, Kazancoglu and Sagnak (2018); Nuñez-Cacho et al.(2018)

Sustainable design of distribution system; Operational efficiency	Decreasing waste (e.g. solid; liquid/water; hazardous/harmful/toxic)

Circular supply chains slow, close, and narrow resource loops to increase competitive advantage as well as economic, environmental, and operational performance (Geissdoerfer et al., 2017, 2018). The SCC modes of slowing, closing, and narrowing describe the flow of resources and materials as well as how value is created in circular supply chains (Lüdeke-Freund, Gold and Bocken, 2019).

Table 2-6 Practices related to the SCC modes

Supply Chain Process	Practice	SCC mode	Practice Description	Practice Source
Material Sourcing	Source secondary materials	Close resource loops	Replace materials with more abundant secondary materials or renewable ones.	De Angelis, Howard and Miemczyk (2018); Batista et al. (2018); Franco (2017); Genovese et al. (2017); Kalmykova, Sadagopan and Rosado (2018); Kazancoglu, Kazancoglu and Sagnak (2018); Masi et al. (2018); Perey et al. (2018); Spring and Araujo (2017)
Design	Customisation	Narrow resource loops	Products are bespoke and meet the needs and preferences of the customer. This can help reduce waste and prevent over-production.	Kalmykova, Sadagopan and Rosado (2018)
	Design for disassembly	Slow resource loops	Design products in a way that considers disassembly for repair, remanufacturing, recycling.	De Angelis, Howard and Miemczyk (2018); Elia, Gnoni and Tornese (2017); Ghisellini, Cialani and Ulgiati (2016); Govindan and Hasanagic (2018); Kalmykova, Sadagopan and Rosado (2018); Kazancoglu, Kazancoglu and Sagnak (2018); Lieder and Rashid (2016); Masi et al. (2018)
	Design for longevity	Slow resource loops	Design products to last longer, considering the physical and emotional durability.	De Angelis, Howard and Miemczyk (2018); Franklin-Johnson, Figge and Canning (2016); Ghisellini, Cialani and Ulgiati (2016); Kazancoglu, Kazancoglu and Sagnak (2018); Kjaer et al. (2019); Lieder and Rashid (2016); Lüdeke-Freund, Gold and Bocken (2019); Manninen et al. (2018); Spring and Araujo (2017)
	Design for modularity	Slow resource loops	Products are designed to include functional modules so that they can be more easily serviced, repaired or replaced, also upgraded.	Kalmykova, Sadagopan and Rosado (2018); Lieder and Rashid (2016); Lüdeke-Freund, Gold and Bocken (2019); Spring and Araujo (2017)
	Reduce resource use	Narrow resource loops	Design that minimises the amount of materials used, especially toxic or hazardous substances.	Kjaer et al. (2019); Lieder and Rashid (2016); Masi et al. (2018); Reike, Vermeulen and Witjes (2018)

Supply Chain Process	Practice	SCC mode	Practice Description	Practice Source
Production	Eco-efficient production processes/ technology	Narrow resource loops	Manufacturing processes and technology are designed to maximise energy efficiency / minimise waste / minimise water & energy consumption. Use renewable energy sources.	Elia, Gnoni and Tornese (2017); Kalmykova, Sadagopan and Rosado (2018); Kazancoglu, Kazancoglu and Sagnak (2018); Masi et al. (2018); Reike, Vermeulen and Witjes (2018)
Distribution	Reuse/ Resell	Slow resource loops	Resell products, components for same purpose, second-hand.	De Angelis, Howard and Miemczyk (2018); Batista et al. (2018); Govindan and Hasanagic (2018); Kalmykova, Sadagopan and Rosado (2018); Kazancoglu, Kazancoglu and Sagnak (2018); Kjaer et al. (2019); Lüdeke-Freund, Gold and Bocken (2019); Masi et al. (2018); Reike, Vermeulen and Witjes (2018)
	Sustainable design of distribution system	Narrow resource loops	Includes switching to more sustainable modes of transportation, route optimisation or eco-driving. Design packaging material to reduce overall resource use.	Kalmykova, Sadagopan and Rosado (2018); Kazancoglu, Kazancoglu and Sagnak (2018)
Use	Maintenance and Repairs	Slow resource loops	Conduct maintenance, repair activities or product upgrades. The purpose is to extend the product lifetime.	De Angelis, Howard and Miemczyk (2018); Batista et al. (2018); Kalmykova, Sadagopan and Rosado (2018); Kjaer et al. (2019); Lüdeke-Freund, Gold and Bocken (2019); Reike, Vermeulen and Witjes (2018)
	Operational efficiency	Narrow resource loops	Decreasing emissions, resource consumption, waste during use phase	Kalmykova, Sadagopan and Rosado (2018); Kazancoglu, Kazancoglu and Sagnak (2018); Kjaer et al. (2019); Reike, Vermeulen and Witjes (2018)
	Refurbish	Slow resource loops	Overall structure of a complex product remains more or less intact, while a number of components are replaced, repaired, or upgraded.	De Angelis, Howard and Miemczyk (2018); Franklin-Johnson, Figge and Canning (2016); Govindan and Hasanagic (2018); Kalmykova, Sadagopan and Rosado (2018); Kjaer et al. (2019); Lüdeke-Freund, Gold and Bocken (2019); Masi et al. (2018); Reike, Vermeulen and Witjes (2018)
Recovery	Cascading	Close resource loops	Occurs when a product, component, or material are used in an entirely different context and	De Angelis, Howard and Miemczyk (2018); Batista et al. (2018); Kalmykova, Sadagopan and Rosado (2018); Lüdeke-Freund, Gold and Bocken (2019); Masi et al. (2018); Perey et al. (2018)

Supply Chain Process	Practice	SCC mode	Practice Description	Practice Source
			effectively transfer across to a different value chain. For example, when a by-product of a production process is used as an input of a different process.	
	Recycling	Close resource loops	Recovery usable materials from waste stream, use of recovered materials for production inputs.	De Angelis, Howard and Miemczyk (2018); Batista et al. (2018); Elia, Gnoni and Tornese (2017); Franklin-Johnson, Figge and Canning (2016); Govindan and Hasanagic (2018); Kalmykova, Sadagopan and Rosado (2018); Kazancoglu, Kazancoglu and Sagnak (2018); Kjaer et al. (2019); Lüdeke-Freund, Gold and Bocken (2019); Masi et al. (2018); Lüdeke-Freund, Gold and Bocken (2019); Masi et al. (2018); Reike, Vermeulen and Witjes (2018)
	Remanufacturing	Close resource loops	Product is disassembled, checked, cleaned and repaired in a full industrial process. Expected product lifetime to be similar to new product.	De Angelis, Howard and Miemczyk (2018); Batista et al. (2018); Elia, Gnoni and Tornese (2017); Franklin-Johnson, Figge and Canning (2016); Ghisellini, Cialani and Ulgiati (2016); Govindan and Hasanagic (2018); Kalmykova, Sadagopan and Rosado (2018); Kazancoglu, Kazancoglu and Sagnak (2018); Kjaer et al. (2019); Lieder and Rashid (2016); Lüdeke-Freund, Gold and Bocken (2019); Masi et al. (2018); Reike, Vermeulen and Witjes (2018); Spring and Araujo (2017)

There are fifteen practices related to the SCC modes (see Table 2-6). These can be classified according to the supply chain processes along the product lifecycle: material sourcing, design, production, distribution, use, and recovery. During the material sourcing and recovery processes, the practices are focused around closing resource loops. In the other processes, however, the practices slow and narrow resource loops.

2.4.2 PSSs and SCC

The review focused on identifying SCC practices implemented in the different PSSs: product-oriented, use-oriented, and result-oriented (see Table 2-7).

Table 2-7 Evidence of SCC practices in empirical PSS papers

PSS	Source	Industry	Geo-graphy	SCC Practices														
				Materials Sourcing	Design					Production	Distribution		Use			Recovery		
				*	***	**	**	**	***	***	**	***	**	***	**	*	*	*
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Product-Oriented PSS	Baines et al. (2009b)	Capital equipment	Europe										×		×			
	Bastl et al. (2012)	Capital equipment	Europe										×		×			
	Chakkol et al. (2014)	Automotive	Europe										×	×				
	Colen and Lambrecht (2013)	Capital equipment	Europe				×						×					×
	Corvellec and Stål (2017)	Textiles	Europe								×		×				×	
	Durugbo (2013)	Capital equipment	Europe										×					
	Finne and Holmström (2013)	Capital equipment	Europe										×		×			
	Gebauer, Paiola and Saccani (2013)	Capital equipment	Europe										×		×			
	Lockett et al. (2011)	Capital equipment	Europe										×					
	Pal (2016)	Textiles	Europe										×				×	
	Reim, Parida and Sjödin (2016)	Construction equipment	Europe										×					
	Smith, Maull and Ng (2014)	Capital equipment	Europe										×					
	Sundin, Lindahl and Ijomah (2009)	Construction equipment	Europe				×						×					×
	Yang et al. (2018)	Capital equipment	Asia										×					
Use-oriented PSS	Bressanelli et al. (2018)	Household appliances	Europe										×	×	×		×	×

PSS	Source	Industry	Geo-graphy	SCC Practices														
				Materials Sourcing	Design					Production	Distribution		Use			Recovery		
				*	***	**	**	**	***	***	**	***	**	***	**	*	*	*
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Corvellec and Stål (2017)	Textiles	Europe								×						×	
	Fargnoli et al. (2018)	Medical equipment	Europe			×							×					
	Geissdoerfer et al. (2018)	Bicycle	S. America				×						×					
	Johnson and Mena (2008)	Material handling equipment	Europe								×		×					
	Lindahl, Sundin and Sakao (2014)	Construction equipment	Europe				×											×
	Linder and Williander (2017)	Bicycle	Europe										×					×
	Pal (2016)	Textiles	Europe										×		×			
	Sousa-Zomer et al. (2018a, 2018b)	Household appliances	S. America	×		×	×			×	×	×	×			×	×	
	Sundin and Bras (2005)	Household appliances	Europe										×					×
	Yang et al. (2018)	Capital equipment	Asia								×		×				×	×
Result-Oriented PSS	Baines and Lightfoot (2013)	Transportation equipment, automotive, construction equipment and office equipment	Europe/ N. America					×					×					×
	Batista et al. (2018)	Defence	Europe										×					
	Brax and Jonsson (2009)	Capital equipment	Europe										×					
	Corvellec and Stål (2017)	Textiles	Europe								×						×	

PSS	Source	Industry	Geo-graphy	SCC Practices															
				Materials Sourcing	Design					Production	Distribution		Use			Recovery			
				*	***	**	**	**	***	***	**	***	**	***	**	*	*	*	
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
	Datta and Roy (2011)	Defence	Europe										×	×					
	Gebauer, Haldimann and Saul (2017)	Construction equipment, capital equipment	Europe								×		×	×	×				
	Gebauer, Paiola and Saccani (2013)	Transportation equipment, capital equipment	Europe		×								×						
	Johnson and Mena (2008)	Aerospace, capital equipment, automotive, transportation equipment	Europe			×		×			×		×					×	
	Johnstone, Dainty and Wilkinson (2009)	Aerospace	Europe										×						
	Kapletia and Probert (2010)	Aerospace	Europe										×						
	Kleemann and Essig (2013)	Defence	Europe										×						
	Lindahl, Sundin and Sakao (2014)	Paper and pulp	Europe	×							×						×		
	Manninen et al. (2018)	Household appliances	Europe			×					×		×	×	×		×	×	
	Ng, Maull and Yip (2009)	Defence	Europe										×						
	Oghazi and Mostaghel (2018)	Medical equipment	Europe										×						
	Rabetino et al. (2015)	Capital equipment	Europe		×								×				×		

PSS	Source	Industry	Geo-graphy	SCC Practices														
				Materials Sourcing	Design					Production	Distribution		Use			Recovery		
				*	***	**	**	**	***	***	**	***	**	***	**	*	*	*
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Saccani, Visintin and Rapaccini (2014)	Household appliances	Europe		×								×					
	Settanni et al. (2017)	Defence	Europe										×					
	Smith, Maull and Ng (2014)	Capital equipment	Europe		×								×	×				
	Story et al. (2017)	Transport equipment, medical equipment	Europe										×					
	Sundin and Bras (2005)	Material handling equipment	Europe		×	×					×		×		×		×	×
	Sundin, Lindahl and Ijomah (2009)	Material handling equipment	Europe		×	×	×	×	×				×					×
	Yang et al. (2018)	Capital equipment	Asia		×						×		×			×	×	×

Notes: 1. In the third row in the header: * = Closing, ** = Slowing, *** = Narrowing; 2. In the fourth row of the header: 1 is Source secondary materials; 2 is Customisation; 3 is Design for disassembly; 4 is Design for longevity; 5 is Design for modularity; 6 is Reduce resource use; 7 is Eco-efficient production processes/ technology; 8 is Reuse/ Resell; 9 is Sustainable design of distribution system; 10 is Maintenance and Repairs; 11 is Operational efficiency: 12 is Refurbish; 13 is Cascading; 14 is Recycling; 15 is Remanufacturing.

The identified practices in the fourteen *product-oriented PSS* cases are almost all associated with the slowing of resource loops. Maintenance and repair occurred in all fourteen cases, while refurbishing was mentioned in four. In one case, however, the manufacturer of complex-engineered products decided against refurbishing components and instead fit new ones to boost sales (Lockett et al., 2011). The review also identified design practices associated with the slowing of resource loops. In the case of soil compactors in Sweden, the company aimed to save costs by designing their products to increase the service intervals and to decrease the need for maintenance and remanufacturing (Sundin, Lindahl and Ijomah, 2009). In a capital equipment case, the manufacturer designed products for reliability and maintainability to ensure that the product had a low failure rate and that service activities could be conducted with ease and at low cost (Colen and Lambrecht, 2013). The dominance of practices associated with the slowing of resource loops can be explained by the sample's focus around maintenance and technical support services. The review also identified some practices associated with closing resource loops. Two cases mentioned remanufacturing of products and components, which were implemented to facilitate spare-part provision and to rejuvenate the employed equipment (Colen and Lambrecht, 2013; Sundin, Lindahl and Ijomah, 2009). Recycling activities were only mentioned in cases of textile PSSs, in which H&M and other companies implemented take-back schemes for clothes to either use them to produce lower value textiles or give them to charity (Corvellec and Stål, 2017; Pal, 2016). One case mentioned training activities to increase resource efficient product use (Chakkol et al., 2014).

Even though there are two cases less in *use-oriented PSS* (twelve) compared to product-oriented PSSs, the total identified practices in this sample increased from 25 to 33. As with product-oriented PSSs, the most widely mentioned activities were around the slowing of resource loops, especially maintenance and repairs. In comparison to the previous sample, however, there were more design related practices (Fargnoli et al., 2018; Geissdoerfer et al., 2018; Sousa-Zomer et al., 2018a). In addition, the amount of practices associated with closing resource loop

increased. Recycling was identified in four cases, while remanufacturing occurred in five. In a bicycle case in Sweden, however, the manufacturer failed to expand its circular business model based on remanufacturing beyond the pilot phase due to the difficulty of forecasting demand for multiple product lifecycles (Linder and Williander, 2017). Cascades were also mentioned in the case of a water filtration equipment manufacturer in Brazil, where the firm created a spin-off, to sell by-products and waste resources to external partners (Sousa-Zomer et al., 2018a). This case had the most identified practices across all empirical PSS papers. For example, they also narrowed resource loops by reducing the use of chemicals in manufacturing processes, using energy-saving production equipment, systematically reducing waste in production, and incorporating environmental aspects into the logistics design (Sousa-Zomer et al., 2018a). Contrary to the other empirical papers in this review, it specifically focused on implementing circularity across the entire supply chain. This can be explained by the manufacturer's strong commitment to sustainability and CE. In one case, the manufacturer supported the customer in the resource efficient use of the product (Bressanelli et al., 2018).

The most practices were identified in result-oriented PSSs (62), which was expected since these are the largest number of cases (24). Similar to the previous two PSS types, the vast majority of practices were around the slowing of resource loops, especially maintenance and repairs. In some, products were also designed for disassembly and for longevity (Manninen et al., 2018; Sundin, Lindahl and Ijomah, 2009). Two practices that were not previously identified were design for modularity and customisation. This was expected, because result-oriented PSSs are less defined and focused on solving specific business needs (Saccani, Visintin and Rapaccini, 2014). Even though customisation is expected to reduce resource use by preventing waste and overproduction (Kalmykova, Sadagopan and Rosado, 2018), Yang et al. (2018) note that product customisation made remanufacturing and recycling costlier, thereby presenting a potential trade-off between customisation and the closing of resource loops. There were a number of practices identified with the closing of resource loops. In the case of a gas generator manufacturer in China providing services around industrial gases, the

company was able to cascade by-product gases to other supply chains (Yang et al., 2018). According to them, this was only possible in result-oriented PSSs, since the manufacturer was able to control the product use phase. This sample identified the highest number of practices associated with operational efficiency in the use phase. This can be explained by the manufacturer having control over product use to deliver results or by implementing comprehensive risk and reward sharing schemes, which can help ensure a customer's efficient product use (Gebauer, Haldimann and Saul, 2017; Smith, Maull and Ng, 2014).

Overall, the results in this section show that there is an increase in amount and type of SCC practices identified as PSSs move from product- to result-oriented. This can be explained by: 1) The manufacturer internalising operational risks, resulting in the need for higher product reliability and maintainability (Colen and Lambrecht, 2013; Reim, Parida and Sjödin, 2016); 2) Product ownership retention incentivising manufacturers to maximise value capture across the product lifecycle (Yang et al., 2018); 3) Having more information and control regarding the quantity and quality of product flows compared to traditional sales business models (Sundin and Bras, 2005; Yang et al., 2018).

2.4.3 Contextual factors affecting SCC

This section reviews the contextual factors that can influence the implementation of SCC practices. Thirteen factors were identified through the content analysis of the CE and PSS papers. These factors were classified into six categories based on their nature and meaning (see Table 2-8).

Table 2-8 Contextual factors affecting SCC

Category	Contextual Factor	Description	Effect on SCC practices	Source
Economic attractiveness of SCC	Cost impact	Additional costs for implementing SCC practices.	Negative – by increasing operational, planning, and/or sourcing costs. Positive – by reducing maintenance and/or after-sale service costs.	Colen and Lambrecht (2013); Franco (2017); Govindan and Hasanagic (2018); Lieder and Rashid (2016); Linder and Williander (2017); Masi et al. (2018); Rizos et al. (2016); Yang et al. (2018)
	Growth opportunities	Economic opportunities stemming from selling products multiple times.	Positive – by creating new revenue sources.	Gebauer, Haldimann and Saul (2017); Reim, Parida and Örtqvist (2015); Sundin, Lindahl and Ijomah (2009)
	Risk of cannibalisation	Risk that circular practices may reduce product sales.	Negative – by threatening sales.	Linder and Williander (2017); Lockett et al. (2011)
Firm sustainability strategy	Firm sustainability strategy	Firm internal sustainability strategy and circular economy policy.	Positive – by increasing the organisational and individual commitment to SCC practices.	Corvellec and Stål (2017); Geissdoerfer et al. (2018); Masi, Day and Godsell (2017); Perey et al. (2018); Rizos et al. (2016); Sousa-Zomer et al. (2018b)
Policy and societal environment	Customer acceptance	Customer acceptance of innovative business models and/or refurbished/remanufactured products.	Negative – due to customer perception that refurbished/remanufactured products have inferior quality.	Govindan and Hasanagic (2018); Lieder and Rashid (2016)
	Laws and regulations	Relevant existing laws and regulations.	Negative – by preventing waste recovery; stifling collaboration through competition laws. Positive – by supporting practices, for example, through tax benefits and/or recycling requirements.	De Angelis, Howard and Miemczyk (2018); Brown and Bajada (2018); Fargnoli et al. (2018); Franco (2017); Genovese et al. (2017); Lieder and Rashid (2016); Linder and Williander (2017); Masi, Day and Godsell (2017)
	Waste management infrastructure	Existing infrastructure for collection and processing of wastes.	Positive – by providing the necessary infrastructure to	Corvellec and Stål (2017)

			implement collection, recovery activities.	
Product category	Product characteristics	Includes product lifetime, complexity of product designs, as well as functional, economic and aesthetic deterioration over time.	Positive – by having stable technology; a core that can be reused; low deterioration of economic value. Negative – by limiting recovery options (e.g. material restrictions); being subject to fashion changes.	Franco (2017); Ghisellini, Cialani and Ulgiati (2016); Linder and Williander (2017); Andreu, cited in Sundin, Lindahl and Ijomah (2009)
Supply chain relationships	Cross-sector supply chain collaboration	Actors engage in collaboration with actors outside their supply chain to prevent impacts, resources from becoming wastes.	Positive – by enabling the development of cascading resource flows.	De Angelis, Howard and Miemczyk (2018); Batista et al. (2018); Koh et al. (2017); Perey et al. (2018)
	Supply chain integration	Degree to which intra- and inter-organisational processes are managed collaboratively.	Positive - by facilitating information sharing and alignment of actors towards desired outcomes.	Baines and Lightfoot (2013); Batista et al. (2018); Bernon, Tjahjono and Ripanti (2018); Chakkol et al. (2014); Lockett et al. (2011); Smith, Maull and Ng (2014); Spring and Araujo (2017)
Technology	Digital technologies	Digital technologies around the internet of things, big data, tracking and monitoring.	Positive – by providing information on asset use, condition, and location; facilitating maintenance, repair activities; providing information to improve product design; facilitating recovery.	Baines and Lightfoot (2013); Bressanelli et al. (2018); Spring and Araujo (2017)

- The *economic attractiveness of SCC practices* can have a positive effect on SCC. For example, Toyota Material Handling Group in Sweden increased its revenues by selling remanufactured forklift trucks it previously used in its PSS (Sundin, Lindahl and Ijomah, 2009). In addition, designing products for longevity can help reduce maintenance costs (Colen and Lambrecht, 2013). But economic aspects can also have a negative effect on SCC. In one PSS case of gas generators in China, the potential value from end-of-life recovery was too little compared to the costs due to the long product lifetime and high degree of customisation (Yang et al., 2018). Another potential negative effect on SCC can stem from the risk of cannibalising existing product or component sales (Linder and Williander, 2017). The financial costs and risks of increasing SCC can particularly inhibit small- and medium-sized enterprises (SMEs), due to a lack of capital (Rizos et al., 2016).
- The *firm sustainability strategy* can positively affect the implementation of SCC practices (Rizos et al., 2016). This manifested itself in the case of a use-oriented PSS of water filtration equipment in Brazil (Sousa-Zomer et al., 2018a). The manufacturer received multiple awards for its commitment to sustainability, which was exemplified by the implementation of circular practices across all supply chain processes.
- The *policy and societal environment* can negatively affect circularity through customer concerns over the quality of refurbished or remanufactured products (Lieder and Rashid, 2016) as well as through laws and regulations that stifle waste recovery and/or cross-sector collaboration (De Angelis, Howard and Miemczyk, 2018; Govindan and Hasanagic, 2018). Laws and regulations can also positively influence SCC through tax benefits and/or recycling requirements (Brown and Bajada, 2018; Lieder and Rashid, 2016). In addition, a well-developed waste management sector can provide

the necessary infrastructure to implement SCC practices (Corvellec and Stål, 2017).

- The *product category* can have a positive effect on SCC. Remanufacturing, for example, is considered most beneficial when the product has a core that can be restored, the associated technology is relatively stable, it can be easily disassembled and restored, and has relatively high recoverable value (Andreu, cited in Sundin, Lindahl and Ijomah, 2009). Nevertheless, it can also have a negative effect if the materials are unsuitable for recycling, too complex or when the product is subject to fashion changes (Ghisellini, Cialani and Ulgiati, 2016; Linder and Williander, 2017).
- *Supply chain relationships* can have a positive effect on SCC through cross-sector collaboration and the implementation of cascading resource flows (De Angelis, Howard and Miemczyk, 2018). In addition, supply chain integration can positively affect SCC by enabling information sharing and the alignment of actors towards desired circularity outcomes. This is exemplified by sharing of materials and information between manufacturer and customer to minimise product failure (Fargnoli et al., 2018; Smith, Maull and Ng, 2014). The review also identified a number of PSS cases studies, where misalignment across the supply chain and resistance to share information prevented suppliers from effectively supporting maintenance services (Finne and Holmström, 2013; Lockett et al., 2011).
- The use of digital *technology*, such as internet of things or tracking and monitoring, can have a positive effect on SCC by facilitating maintenance and repair activities as well as facilitating product design improvements or facilitating recovery (Bressanelli et al., 2018; Spring and Araujo, 2017).

2.4.4 PSSs and SCC – a conceptual map

Based on the literature review presented, a conceptual map is presented (see Figure 2-3).

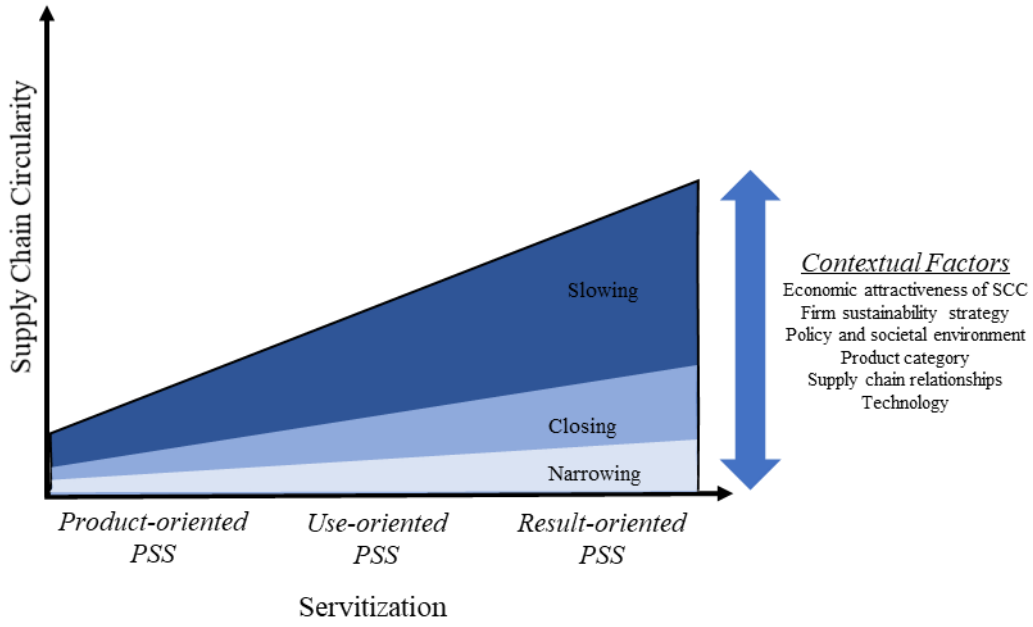

Figure 2-3 Conceptual map

The conceptual map posits that SCC is highest in result-oriented PSSs followed by use-oriented PSSs and finally product-oriented PSSs. The first SCC mode is the slowing of resource loops. In product-oriented PSSs, maintenance practices help increase the durability of the products and reduce the failure rate (Colen and Lambrecht, 2013). In use-oriented PSSs, the slowing of resource loops increases. Here, the manufacturer retains ownership and is thus incentivised to prolong the product lifecycle through repairs and maintenance (Bressanelli et al., 2018; Reim, Parida and Örtqvist, 2015). The slowing of resource loops is increased by refurbishing and reselling products in secondary markets (Gebauer, Haldimann and Saul, 2017). In result-oriented PSSs, the slowing potential is the highest, because the manufacturer is responsible for the delivery of specific outcomes. This is exemplified by extensive predictive and preventive maintenance as well as faster fault diagnostics and rectification (Baines and

Lightfoot, 2013; Johnstone, Dainty and Wilkinson, 2009). This argument leads to the following proposition:

Proposition 1: The slowing of resource loops is the highest in result-oriented PSSs followed by use-oriented PSSs, and finally product-oriented PSSs.

The second SCC mode is closing resource loops. In product-oriented PSSs, the review identified practices around the remanufacturing or recycling of old components that were recovered in repair or maintenance activities (Colen and Lambrecht, 2013). In use-oriented PSSs, the manufacturer retains product ownership and is incentivised to recover products, components, and materials to maximise profits (Yang et al., 2018). The potential for closing resource loops increases in result-oriented PSSs because the manufacturer has more control over resource flows in the use phase (Yang et al., 2018). This argument leads to the following proposition:

Proposition 2: The closing of resource loops is the highest in result-oriented PSSs followed by use-oriented PSSs, and finally product-oriented PSSs.

The third SCC mode is narrowing resource loops, which is comparable to increasing resource efficiency. In product-oriented PSSs, there is limited potential for narrowing resource loops, since the manufacturer has no formal interaction or control on the customer's use of the product. In use-oriented PSSs, the PSS provider retains ownership, monitors user behaviour and supports the customer in efficient and sustainable usage (Bressanelli et al., 2018). In result-oriented PSSs, the potential for narrowing resource loops is the highest. Here, the manufacturer can control how products are used and can find innovative and efficient ways to deliver results (Reim, Parida and Örtqvist, 2015; Yang et al., 2018). In addition, these offerings are highly customised, which can potentially prevent waste and over-production (Kalmykova, Sadagopan and Rosado, 2018). This argument leads to the following proposition:

Proposition 3: The narrowing of resource loops is the highest in result-oriented PSSs followed by use-oriented PSSs, and finally product-oriented PSSs.

Finally, the review suggests that the strength of the application of the SCC practices differs. This was determined by the number of practices that were identified in the empirical PSS papers (see Table 2-7). The dominance of the slowing of resource loops can be explained by the strategic importance of product reliability and maintainability in the delivery of PSSs, especially result-oriented PSSs (Baines and Lightfoot, 2013; Colen and Lambrecht, 2013). In comparison, there were significantly fewer identified practices around closing resource loops. Evidence of difficulties in implementing remanufacturing and recycling (Linder and Williander, 2017; Yang et al., 2018) support the notion that PSS adoption is not a guarantee for increased circularity (Kjaer et al., 2019). This argument leads to the following proposition:

Proposition 4: The main effect of servitization on SCC stems from increased slowing, followed by closing, and finally narrowing resource loops.

This model identifies a number of contextual factors that can influence the degree to which PSSs affects SCC (see Table 2-8).These are represented by the up- and down- ward facing arrow on the right side of the model and are as follows: 1) Economic attractiveness of SCC; 2) Firm sustainability strategy; 3) Policy and societal environment; 4) Product category; 5) Supply chain relationships; 6) Technology. As mentioned in section 4.3, the contextual factors can influence the implementation of SCC practices. This argument leads to the following proposition:

Proposition 5: Contextual factors can have positive or negative effects on the relationship between servitization and SCC.

2.5 Discussion and conclusion

2.5.1 Research synthesis

The CE concept considers PSSs around renting, leasing, and sharing as a core enabler of SCC. When customers only pay for the service they receive and manufacturers retain product ownership, the manufacturer will aim to reduce the amount of resources used (Reim, Parida and Örtqvist, 2015; Vezzoli et al., 2015).

To the authors' knowledge, this is the first attempt to synthesise existing research on PSS implementation and its relationship to SCC.

This study answers the first review question ('What is SCC?') by identifying and linking the principal modes of SCC slowing, closing, and narrowing resource loops and their performance indicators with fifteen supply chain practices. This contributes to previous conceptualisations of SCC (De Angelis, Howard and Miemczyk, 2018; Batista et al., 2018), which focused predominantly on defining and delineating circular supply chains from other concepts found in the literature, such as closed-loop supply chains. Specifically, it further elaborates on the SCC concept, by identifying fifteen SCC practices that are associated with the slowing, closing and narrowing of resource loops. In addition, it contributes by providing an approach to assessing SCC, a need that was previously identified (Elia, Gnoni and Tornese, 2017).

In regard to the second question ('How do PSSs affect SCC?'), the review synthesises the effects of servitization on SCC. The findings are translated into a conceptual map (see Figure 2/3 and five propositions. They confirm previous claims that the SCC potential increases as manufacturers move from offering product-oriented to result-oriented PSSs and retain product ownership (Tukker, 2004, 2015; Vezzoli et al., 2015). The fourth proposition is based on the finding that more practices are identified as business models move from product- to result-oriented PSSs. The relative lack of practices associated with closing and narrowing resource loops supports the notion that PSS adoption is not a guarantee for increased circularity (Kjaer et al., 2019).

This ties into the findings for the third review question ('What contextual factors affect the implementation of SCC?'). The review contributes new knowledge by identifying a range of contextual factors that can positively and negatively influence the implementation of SCC practices. These are classified into: 1) Economic attractiveness of SCC circularity; 2) Firm sustainability strategy; 3) Policy and societal environment; 4) Product category; 5) Supply chain relationships; 6) Technology. These findings are expressed in the fifth proposition.

2.5.2 Theoretical implications

This review contains a plethora of theoretical implications. It links the modes of SCC, namely slowing, closing, and narrowing to practices, resulting in the need to be harmonised with traditional measures and metrics used for efficient and effective supply chain management (Sambasivan, Nandan and Mohamed, 2009). The findings demonstrate the potential of servitization and PSSs contribute to SCC. Nevertheless, the scarcity of SCC practices suggests that there is still potential for the SCC concept to guide upstream and downstream process and product innovation in servitized supply chains (Walters and Rainbird, 2007). The review gives insights into the various contextual factors that may affect how a manufacturer's servitization strategy contributes to SCC. In doing so, it begins to bridge a previously identified gap in the literature (Reim, Parida and Örtqvist, 2015). One finding from the review is that an organisation's strategy and culture around sustainability can potentially affect SCC implementation (Sousa-Zomer et al., 2018b). This ties into existing findings on the effect of organisational culture on supply chain strategy formulation and implementation (Roh, Hong and Park, 2008).

2.5.3 Practical implications

This review bridges the gap between theory and practice in two ways: Firstly, it provides comprehensive empirical evidence about the effect of servitization and PSS implementation on SCC, thereby validating the theoretical claims made about this relationship. This study impacts upon society, because it highlights the need to move away from ownership- to access- or functionality-based business models in the transition to a more sustainable and circular economy. It helps inform policy-makers on the importance of facilitating the implementation of PSSs for SCC. The study provides practitioners with a framework to increase SCC through PSSs. Secondly, the review gives insight into the various contextual factors that may affect how a manufacturer's servitization strategy contributes to SCC. This gives PSS providers a roadmap to implement new business models and to reduce the uncertainties related to their implementation (Linder and

Williander, 2017). It also provides governments with insights into the circumstances required for SCC in PSSs and can therefore help inform effective policy-making.

2.5.4 Research limitations

The study has a few limitations to be considered. Firstly, this study draws on a body of literature around circular PSS implementation, which is still nascent and currently emerging. At present, there are few empirical studies that focus specifically on the relationship between PSSs and SCC. This has implications for the findings around the practices associated with the closing and narrowing of resource loops. One possible explanation for the relative lack of empirical evidence is that these practices are not directly related to the provision of service outcomes. Slowing resource loops on the other hand helps ensure a product's functionality and is therefore critical to a successful service delivery. As a result, existing studies may have simply not focused on aspects related to closing and narrowing resource loops in servitization and PSS implementation. Another possible explanation is that the slowing of resource loops is easier to grasp and to assess than the closing or narrowing of resource loops. Secondly, the review focused on peer-reviewed articles written in English, thereby not considering outputs published in other languages.

2.5.5 Recommendations for future research

This review provides the following future research avenues:

- The present study developed a conceptual map of the relationship between PSSs and SCC, which needs to be tested and empirically validated, for example, through conducting case study or survey research.
- The effect of PSS implementation on SCC can vary based on contextual factors. Further research is recommended to examine these contextual factors and understand the extent of their effect. In particular, the role of firm sustainability strategy provides an interesting

avenue for further research, due to the lack of empirical evidence from firms that are not sustainability-oriented.

- The majority of articles in this review employed qualitative research methods. Quantitative studies, such as surveys, are needed to further evaluate the link between PSS business models and specific circularity practices.
- Finally, future research could expand on the selection of manufacturing firms. For example, it could investigate the potential effect of the economic attractiveness of SCC, by investigating the role that firm size has on the relationship between PSSs and SCC. This could be done, for example, by scrutinising small and medium-sized enterprises (SMEs). Finally, more studies are needed beyond the European context as most studies in this review were predominantly from Europe.

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3 Product-service systems and supply chain circularity practices: The moderating effect of firm size and internal environmental orientation (Paper 2)

Abstract

The circular economy (CE) literature assumes that product-service systems (PSSs) lead to supply chain circularity (SCC) practice implementation. To date, there has been little empirical evidence of this link. This paper tests a model delineating the relationships between PSSs, SCC practices, firm size and internal environmental orientation. A survey was conducted among 206 manufacturing firms in the United Kingdom (UK). Partial Least Squares Structural Equation Modelling (PLS-SEM) was conducted to evaluate the model. This study shows that product-oriented PSSs leads to the implementation of practices associated with the slowing of resource loops, use-oriented PSS leads to the implementation of practices associated with the closing and result-oriented PSS leads to the implementation of practices associated with the slowing, closing and narrowing of resource loops. This provides a first attempt at theorising how the transition to SCC occurs in manufacturing firms undergoing servitization. It also finds that firm size and internal environmental orientation do not moderate this relationship. The developed measurement items can assist manufacturers in benchmarking the implementation of SCC practices. Future research could examine the moderating effect of further contextual factors or take a longitudinal perspective to identify patterns in SCC practice implementation.

Keywords Circular economy, product-service system (PSS), supply chain, partial least squares structural equation modelling (PLS-SEM)

3.1 Introduction

The circular economy (CE) concept provides a framework for moving from the current linear take-make-dispose economy to a restorative and regenerative system that creates economic and environmental benefits, by keeping products and materials at highest utility and value through long-lasting design, repair, reuse, refurbishment, and recycling (Ellen MacArthur Foundation, 2013; Geissdoerfer et al., 2017, 2018). In recent years, the CE concept has been integrated into the supply chain management literature. Circular supply chains slow, close, and narrow resource loops to increase competitive advantage as well as economic, environmental, and operational performance (Geissdoerfer et al., 2018). The transition to supply chain circularity (SCC) is a key policy concern in the European Union (EU) and the UK, as demonstrated by recent Circular Economy Policy Packages (DEFRA UK, 2020; European Commission, 2020). One particular focus area is the manufacturing sector. The CE concept proposes that manufacturing firms should innovate their business models from offering products to selling services (Tukker, 2015). It is argued that when manufacturers innovate from selling products to delivering so-called product-service systems (PSSs), they will maximise resource efficiency and optimise resource utilisation to increase their profitability (Hofmann, 2019; Tukker, 2015), hence contributing to SCC.

The link between PSSs and SCC practice implementation is based on the logic of the natural resource-based view (NRBV) (Hart, 1995). According to this theory, firms are able to gain competitive advantage from implementing pro-environmental practices. From the perspective of the NRBV, companies implement SCC practices to create value, for example through cost reduction or differentiation (Hart, 1995; Rosa, Sassanelli and Terzi, 2019). In the case of PSSs, manufacturers are able to implement SCC practices, because they take responsibility for more activities that were previously handled by the customer, such as maintenance and repair (Yang et al., 2018).

Given the key role that PSSs are expected to play in the transition to a CE in the UK and the EU, it is necessary to understand their potential to contribute to SCC

practice implementation. Currently, several gaps remain in this area. Prior research on this relationship reveal inconclusive results, with some advocating strong positive relationships (Yang et al., 2018), and others treading a more cautious line (Corvellec and Stål, 2017; Matschewsky, 2019). This is because evidence for the link between PSSs and SCC practices mainly emerges from qualitative or conceptual studies, thus requiring further confirmation from larger-scale quantitative research.

Moreover, differences among groups of firms have often been neglected. Specifically, the little evidence for the impact of PSSs on SCC in traditional manufacturing firms focuses on the context of large manufacturing firms (Matschewsky, 2019; Yang et al., 2018). Nevertheless, small- and medium-sized enterprises (SMEs) play a crucial part in the transition to CE (Rizos et al., 2016). Compared to larger firms, SMEs may face significant barriers in their transition to CE, due to their limited resources, such as a lack of capital or support from their supply and demand network (Rizos et al., 2016). In addition, the role of company culture and firms' commitment to environmental protection needs to be examined more closely. Corporate culture is a key firm-level factor in the successful transition to CE (Kirchherr et al., 2018; Rizos et al., 2016). In the case of PSSs, however, most manufacturing firms pursue services for strategic and commercial, not environmental reasons (Baines and Shi, 2015). Compared to traditional manufacturers, environmentally-oriented firms may be more aware of circular best practices in PSS design (Matschewsky, 2019).

Finally, there are no previously developed measurement items specifically for SCC practices. While constructs exist for related supply chain concepts, such as sustainable supply chains (Abdul-Rashid et al., 2017) or green supply chains (Zhu and Sarkis, 2004), none exists for SCC. Hence, this study aims to address such research gaps that the prior literature has until now failed to cover. Therefore, this paper proposes a theoretical model that includes PSSs, SCC practices, as well as the contextual factors firm size and internal environmental orientation as moderators. This work aims to answer the following questions:

1) What impact do PSSs have on the implementation of SCC practices?;

2) Does firm size moderate the relationship between PSSs and SCC practice implementation?

3) Does internal environmental orientation moderate the relationship between PSSs and SCC practice implementation?

This chapter has five sections. Following this introduction: Section 3.2 lays out the conceptual framework of this research, proposing the hypotheses and the conceptual map. Section 3.3 explains the research methodology, the sample information, and the data analysis. Section 3.4 presents the results. Section 0 presents main conclusions, managerial implications, and limitations of the study as well as potential opportunities for further research.

3.2 Literature review and hypotheses development

In the current context of rising environmental ambitions and requirements, there is a need for industry to conceptualise an economically, environmentally, and socially sustainable industrial model. As a result, researchers and practitioners increasingly focus on the conceptualisation, design, and delivery of sustainable products and services (Smart et al., 2017). Both of the two key concepts involved in this research, PSSs and SCC practices, share the same unifying dialogue in the industrial sustainability literature and focus on creating sustainable value through innovation (Smart et al., 2017).

PSSs emerged in the 1990s and they are part of a wider literature and domain of servitization research that was recognised as a paradigm to change business models from selling products to selling services to increase competitiveness of manufacturing firms (Kowalkowski, Gebauer and Oliva, 2017; Luoto, Brax and Kohtamäki, 2017; Rabetino et al., 2018). The PSS literature is an element of this literature that is specifically focused on sustainability (Rabetino et al., 2018). It builds on the idea that transitioning away from selling products to selling functionality incentivises manufacturers to dematerialise the offering (Rabetino et al., 2018; Tukker, 2004). There are three types of PSSs, which are classified as moving from a product focus to a service focus: product-oriented, use-oriented, and result-oriented (Tukker, 2004).

Similar to the PSS concept, circular supply chains are also an approach to sustainability that focus on making better use of resources and waste to create economic and environmental value (Geissdoerfer et al., 2017, 2018; Genovese et al., 2017). Circular supply chains integrate the supply chain and the surrounding business ecosystem to slow, close, and narrow resource flows to ultimately create economic and environmental value (Batista et al., 2018; Geissdoerfer et al., 2018). Practices associated with slowing of resource use focus on the length of time for which a product is retained in a product system (Bocken et al., 2016). This can be achieved through designing long-life products and through product life extensions, such as maintenance, repair or refurbishing (Bocken et al., 2016). Closing resource loops focuses on closing flows between post-use and production, for example, through recycling or cascading by-products (Bocken et al., 2016). Narrowing the resource impact focuses on reducing the use of resources per product (Bocken et al., 2016). It focuses on reducing resource use per unit of value, for example, through more efficient product use phases (Bocken et al., 2016).

The underlying theoretical framework builds on the natural resource-based view of the firm (NRBV) (Hart, 1995). The NRBV argues that the original resource-based view (Barney, 1991) did not consider the impact of the natural environment on the firm. To build a sustainable competitive advantage, firms would need to innovate beyond current economic and organisational practices. SCC practices closely resemble the product stewardship strategy outlined by Hart (1995), which espouses that firms can differentiate themselves by minimising the lifecycle impacts of their products across the entire value chain. One of the strategies for creating sustainable competitive advantage is through product stewardship (Hart, 1995). Product stewardship aims to minimise a product's environmental impacts across the lifecycle and is closely related to circular supply chains or other comparable sustainable supply chain narratives, such as reverse logistics or closed-loop supply chains (Vachon and Klassen, 2008). According to Hart (1995), the implementation of such practices is socially complex, since it relies on information and knowledge exchange between stakeholders and therefore relies

on stakeholder integration to create sustainable competitive advantage (Hart, 1995; Vachon and Klassen, 2008).

The development of the hypotheses on the relationship between PSSs and SCC practice implementation follows this logic. The PSS types contribute differently to SCC practice implementation, due to their varying degrees of manufacturer-customer integration. PSS types with high degrees of manufacturer-customer integration can implement more SCC practices, since the responsibility of manufacturers for activities across the product lifecycle and the information and knowledge exchange between manufacturer and customer increases (Matschewsky, 2019; Östlin, Sundin and Björkman, 2008). Therefore, the manufacturer has the responsibility and incentive to implement SCC practices, especially when these create economic value (Matschewsky, 2019; Yang et al., 2018; Yang and Evans, 2019). The link between PSSs and SCC practices associated with the slowing, closing, and narrowing of resource loops is elaborated more closely in the next section.

3.2.1 The effect of PSSs on SCC practice implementation

In product-oriented PSSs, the product is sold to the customer and enhanced by stand-alone additional services, such as maintenance or extended warranty agreements (Gaiardelli et al., 2014; Tukker, 2004). This creates economic value for both the manufacturer and the customer, since manufacturers are able to create additional revenues, while the customer does not need to develop individual servicing capabilities (Yang et al., 2018). From the perspective of the NRBV, the contribution to SCC practice implementation of product-oriented PSSs is limited to a slowing of resource loops, due to the limited integration of the manufacturer into the product use phase. The manufacturer is responsible for supporting the customer's use of the product, by conducting activities and services, such as maintenance, repairs, warranties or helpdesks (Gaiardelli et al., 2014). As a result, the product-oriented PSSs contribute only to the implementation of practices associated with a slowing of resource loops (Yang et al., 2018). Case study evidence from product-oriented PSSs in machinery and equipment manufacturing showed the implementation of maintenance and repair

activities (Yang et al., 2018) as well as the design of products for ease of maintenance (Reim, Parida and Örtqvist, 2015; Sundin and Bras, 2005). This argument leads to the following hypothesis:

Hypothesis 1: The provision of product-oriented PSSs positively affects the implementation of SCC practices that slow resource loops.

Use-oriented PSSs provide functionality or access, for example, through leasing, renting, or sharing instead of selling products (Gaiardelli et al., 2014; Tukker, 2004). Use-oriented PSSs have a higher degree of manufacturer-customer integration compared to product-oriented PSSs, since the manufacturer is responsible for more activities across the product lifecycle (Gaiardelli et al., 2014). As the manufacturer provides product functionality or access, it is responsible for product availability and it has to implement SCC practices associated with the slowing of resource loops, such as maintenance and repair (Gaiardelli et al., 2014; Tukker, 2004, 2015). From the NRBV perspective, the manufacturer optimises maintenance and service activities to extend product life and ultimately to reduce the costs of delivering PSS (Matschewsky, 2019; Yang et al., 2018). In addition, since the manufacturer retains product ownership, it can also refurbish or it can remanufacture used products and it can resell them on secondary markets (Gebauer, Haldimann and Saul, 2017; Matschewsky, 2019; Yang et al., 2018), slowing and closing resource loops.

The increased integration into the product use phase and retention of product ownership in use-oriented PSSs also results in the implementation of practices associated with the closing of resource loops. Since the manufacturer retains product ownership, it also has information available regarding the timing, location, quantity, and quality of products, which facilitates resource loop closure (Östlin, Sundin and Björkman, 2008). This means that the manufacturer will maximise value recovery at end-of-life, for example through component reuse or recycling (Matschewsky, 2019; Sousa-Zomer et al., 2018; Yang et al., 2018). This argument leads to the following hypothesis:

Hypothesis 2: The provision of use-oriented PSSs positively affects the implementation of SCC practices that slow (H2a) and close (H2b) resource loops.

Result-oriented PSSs deliver a pre-determined result or capability associated with a product (Gaiardelli et al., 2014). These business models have the highest degree of manufacturer-customer integration, since the manufacturer takes on the widest responsibility for product lifecycle activities as well as operational risks, by providing performance guarantees (Gaiardelli et al., 2014). From the perspective of the NRBV, the manufacturer will implement SCC practices to maximise value creation and minimise costs, since all products and parts used to deliver the results become cost centres (Tukker, 2015; Yang and Evans, 2019).

In regard to the implementation of SCC practices associated with the slowing of resource loops, this can include for example, optimised product design, condition-based maintenance activities to prevent product breakdowns (Baines and Lightfoot, 2013). Since the manufacturer also retains product ownership in result-oriented PSSs, it also has information available regarding the timing, location, quantity, and quality of products, which facilitates resource loop closure (Östlin, Sundin and Björkman, 2008; Yang et al., 2018). The biggest difference, in terms of SCC practices, compared to use-oriented PSSs is that manufacturers have more control over the use phase since they either directly control it or closely collaborate with the customer (Gaiardelli et al., 2014). This may lead to the implementation of practices that close resource loops. For example, manufacturers may be able to recycle or cascade any wastes and by-products associated with the product that occur during the use phase (Yang et al., 2018). In addition, result-oriented PSSs also enable the narrowing of resource loops. Since the manufacturer owns and in some cases uses the product to deliver results, it is also incentivised to maximise resource and energy efficiency to reduce costs (Tukker, 2015; Yang and Evans, 2019). This means, for example, finding new innovative ways to maximise resource utilisation in the use phase, such as increasing the washing machine efficiency (Datta and Roy, 2011; Kjaer et al., 2019). This argument leads to the following hypotheses:

Hypothesis 3: The provision of result-oriented PSSs positively affects the implementation of SCC practices that slow (H3a), close (H3b), and narrow (H3c) resource loops.

3.2.2 The moderating effect of firm size

While the literature identifies a number of circular start-ups, the public discourse on case studies of successful CE implementation is dominated by case examples of large companies, such as HP or Philips (Ellen MacArthur Foundation, 2013). Firm size has long been regarded as a major contributor to the implementation of environmental supply chain practices (Zhu et al., 2008). From a resource-based perspective, larger firms have more resources and resource slack to commit to the implementation of SCC practices (Barney, 1991). Firstly, firms that are large and have resource slack have more flexibility in implementing PSSs and the associated practices (Reim, Parida and Örtqvist, 2015). Conversely, Linder and Williander (2017) showed that significant economic uncertainties and risks associated with implementing SCC practices exist in PSSs. Secondly, large firms are more likely to face stakeholder pressures to meet environmental expectations due to their higher visibility (Zhu et al., 2008).

In the case of slowing resource loops, larger firms are likely to have the financial resources to manage and operate the service networks required for slowing (Vermunt et al., 2019), whereas for closing, larger firms are likely going to have more economic flexibility to take on product ownership risks and associated product recovery and reverse logistics costs (Linder and Williander, 2017; Vermunt et al., 2019). Finally, for the narrowing of resource loops, large firms are more likely to have the resources and competencies needed to create the digital competencies required for a narrowing of resources (Lerch and Gotsch, 2015). This argument leads to the following hypotheses:

Hypothesis 4: Firm size positively moderates the relationship between PSSs and the implementation of SCC practices that slow (H4a), close (H4b), and narrow (H4c) resource loops.

3.2.3 The moderating effect of internal environmental orientation

Internal environmental orientation refers to managers' and employees' values and ethical standards in regard to environmental protection (Banerjee, 2002). It can be conceptualised as a pro-environmental culture that manifests itself in a firm's mission statements, policies, procedures, and the training of employees (Banerjee, 2002; Chan et al., 2012). For SMEs, the company environmental culture is the most important enabler in easing the transition to circular supply chains (Rizos et al., 2016). From an organisational learning perspective, the environmental values and beliefs of the corporate leaders will eventually dissipate through the company, its organisational systems, and people (Chan et al., 2012; Egri and Herman, 2000). Intra-organisational learning and knowledge sharing will motivate employees to seek ways to innovate towards more environmentally friendly products and processes (Chan et al., 2012).

In the case of PSSs, the adoption of such business models is not intrinsically sustainable (Pigosso and McAloone, 2016). Instead, sustainability and circularity best practices need to be integrated into the design and development of PSSs (Kjaer et al., 2019; Pigosso and McAloone, 2016). Firms with a high internal environmental orientation will be more aware of necessary tools and guidelines to design PSSs according to SCC principles. For example, environmentally-oriented companies tend to be among the often-cited case examples of firms that are able to successfully slow resource loops in PSSs (Hofmann, 2019). Conversely, a lack of environmental awareness and understanding of SCC principles has been shown to hinder firms from identifying value creation opportunities around the closing and narrowing of resource loops (Yang and Evans, 2019: Yang et al., 2018). Hence, the potential benefits of PSS adoption on SCC practice implementation should be even more salient if a firm has a high rather than a low internal environmental orientation. This argument leads to the following hypotheses:

Hypothesis 5: Internal environmental orientation positively moderates the relationship between PSSs and the implementation of SCC practices that slow (H5a), close (H5b), and narrow (H5c) resource loops.

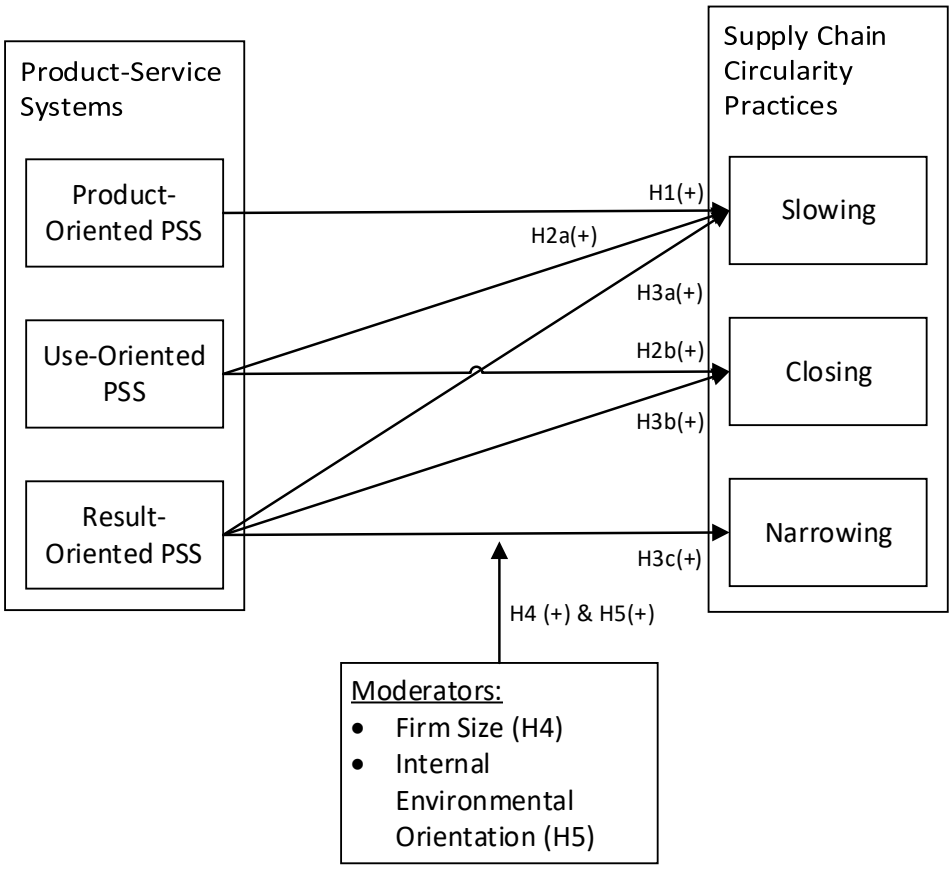


Figure 3-1 Conceptual framework for empirical research

Figure 3-1 shows the overall conceptual framework and delineates the proposed relationships between PSSs, SCC practices, firm size, and internal environmental orientation.

3.3 Methods

3.3.1 Data collection and sample

The hypotheses depicted in Figure 3-1 were empirically tested through a sample of machinery and equipment manufacturing firms in the UK, since these sectors are especially prominent in servitization-related research. This is operationalised through UK Standard Industrial Classification codes (Companies House UK, 2018). Respondents were selected through volunteer opt-in panels from Qualtrics. There are typically two main concerns about this method:

1) Respondents in non-probabilistic approaches may be fundamentally different from the population;

2) Responses may be of lower quality (Zhang et al., 2020). In regard to the first concern, this was deemed acceptable, since this study is of an exploratory nature (Daniel, 2012). Several techniques were employed to identify careless responses, including measuring the response time, reverse worded items, and attention check items (Curran, 2016). In addition, previous studies showed that respondents in opt-in panels take the task of completing surveys more seriously than previously thought (Zhang et al., 2020).

In total, 3089 respondents entered the survey, 2310 did not match the quota, and 573 did not pass the response quality checks. Finally, 206 valid responses were obtained. Some of the responses were only partially completed. Since these had less than 10 per cent of missing data (i.e. 16 responses in this survey), the mean value replacement technique was used (Tsikriktsis, 2005). The demographic characteristics of the respondents are summarised in Table 3-1.

Table 3-1 Demographic characteristics of respondents

Demographic variable	Category	Frequency	%
Industry	Manufacture of computer, electronic, and optical equipment	110	53.4
	Manufacture of machinery and equipment	96	46.6
Respondent Title	Operations/ Supply Chain Manager	73	35.4
	Sales/ Marketing Manager	64	31.1
	Project Manager	35	17
	Director	15	7.3
	Design/ Engineering Manager	11	5.3
	Sustainability Manager	8	3.9
Firm Size	SME	114	55
	Non-SME	92	45
Turnover	Less than £1.8 million	31	15.0
	Between £1.8 and £9 million	67	32.5
	Between £9 and £45 million	51	24.8
	Between £45 and £223 million	24	11.7

Demographic variable	Category	Frequency	%
	More than £223 million	33	16.0
Employees	Less than 10	10	4.9
	Between 10 and 49	36	17.5
	Between 50 and 249	74	35.9
	Between 250 and 5000	52	25.2
	More than 5000	34	16.5

3.3.2 Measures

Multiple items were used to measure each of the constructs, as summarised in Table 3-2. The measurement scales and items were developed in accordance with Churchill's (1979) procedure for developing measures with desirable reliability and validity properties. In the first step, the domain of the constructs and their definitions were specified through a systematic literature review (Kühl et al., 2019). Based on these, an additional literature review was conducted to identify existing survey items for these constructs. Following this step, interviews were conducted with six expert academics (from outside the research team) in CE, Supply Chain Management, and PSSs to validate, refine and reword the initial survey items. The measurement items for all constructs were defined as reflective indicators, since they are a representative sample of a larger possible population of indicators that exist within the conceptual domain of the constructs (Gaiardelli et al., 2014; Kalmykova, Sadagopan and Rosado, 2018). Following this phase, the survey was pre-tested with eight executives working for machinery and equipment manufacturers in the UK. Thus, the face validity of the survey items was established.

To measure PSSs adoption, the measurement scale of Sousa and da Silveira (2017) was identified as the most suitable. Of the reviewed scales, their wording best encapsulated both dimensions of a company's focus on offering services: broadness and emphasis (Homburg, Hoyer and Fassnacht, 2003). They used a five-point Likert scale (1 = "none"; 5 = "high") to ask respondents "to what extent are the following services offered along with the products by the business unit?". The wording around the extent of the offering captures both dimensions of the breadth and the emphasis of the offering. To clarify the option of not offering the

service at all, the N/A (not applicable) option was included (Kohtamaki et al., 2015). The final scale is: To what extent are these services offered by your firm? Please mark a number (Five-point scale: select 0 if you do not offer the service at all; 1 = very low; 2 = low; 3 = medium; 4 = high; 5 = very high). The PSSs items were operationalised using existing classifications (Gaiardelli et al., 2014; Tukker, 2004). The product-oriented PSSs items correspond to Sousa and da Silveira's (2017) category of basic services.

At present, there is no dedicated construct developed for assessing SCC practice implementation. This study employed a five-point Likert scale from green supply chain practice implementation (1 = not considering it; 2 = planning to consider it; 3 = considering it currently; 4 = initiating implementation; 5 = implementing successfully) (Zhu and Sarkis, 2004). The slowing of resource loops focused on supply chain practices that extend product lifetimes, while closing focused on post-production waste and by-product flows (Bocken et al., 2016). For narrowing, there were few specific items related to increasing resource efficiency at the level required in this study. In most cases, the aspects related to narrowing were operationalised as multi-item constructs in their own right, such as sustainable manufacturing processes or supply chain collaboration. To keep the amount of items to a reasonable number, overarching items were formulated that included resource use reduction across the key focal areas in sustainable supply chain management, namely supplier collaboration, product design, production, and downstream collaboration (Golicic and Smith, 2013).

Firm size is operationalised by the number of employees and annual sales (Lai, Wu and Wong, 2013). The items are based on the SME definition of the European Commission (2003). According to this definition, a micro firm has a staff headcount of less than 10 and turnover of up to about £1.8 million. A small firm has a headcount of less than 50 and a turnover of up to £10 million. A medium-sized firm has a headcount of less than 250 and a turnover of up to £50 million. The additional category of more than 5000 employees and turnover of more than £223 million was used to differentiate between large and very large companies (Ałan et al., 2016).

The construct of internal environmental orientation was applied from Banerjee (2002). This scale was chosen because it provided a good summary and overview of the degree to which a firm incorporates environmental concerns into its strategy and decision-making. It was adapted from a seven-point Likert scale to a five-point Likert scale to create a uniform measurement scale.

Table 3-2 Measurement model analysis

Latent Variable	Item	Item Weight	Item Loading	AVE	Cronbach's α	Composite reliability
Notes: PO: Product-oriented PSS; UO: Use-oriented; RO: Result-oriented; SLO: Slowing; CLO: Closing; NAR: Narrowing; FS: Firm Size; IEO: Internal Environmental Orientation.						
PO PSS	Sousa and da Silveira (2017)			0.609	0.783	0.861
PO1	Installation/ commissioning of products	0.309	0.784			
PO2	Provision of spare parts/consumables	0.301	0.787			
PO3	Maintenance and repair of products	0.342	0.851			
PO4	Helpdesk/customer support centre	0.332	0.691			
UO PSS				0.721	0.805	0.886
UO1	Lease of products (with responsibility for product maintenance, repair; long-term agreement; use by a single user) (Gaiardelli et al., 2014)	0.409	0.867			
UO2	Rental/Sharing (with responsibility for product maintenance, repair; short-term agreement; sequential use by different users) (Sousa and da Silveira, 2017)	0.411	0.899			
UO3	Pay-per-use (service provider gives customers access to products; only pays for usage) (Gaiardelli et al., 2014)	0.354	0.777			

Latent Variable	Item	Item Weight	Item Loading	AVE	Cronbach's α	Composite reliability
RO PSS				0.811	0.770	0.895
RO1	Performance-based contract (service provider is paid for delivering results to customer, not individual products or service) (Gaiardelli et al., 2014)	0.625	0.927			
RO2	Outsourcing (service provider takes full responsibility for customer's operating processes) (Gaiardelli et al., 2014)	0.482	0.872			
Slowing Practices				0.468	0.836	0.875
SLOW1	Design of products for durability (Bocken et al., 2016)	0.181	0.676			
SLOW2	Design of products for maintenance and repair (Lai, Wu and Wong, 2013)	0.200	0.776			
SLOW3	Design of products for future modification (adaptability or upgradability) (Bocken et al., 2016)	0.232	0.785			
SLOW4	Design of products for refurbishment or remanufacturing (Abdul-Rashid et al., 2017)	0.179	0.694			
SLOW5	Collection of used products from customers for reuse or resale (Lai, Wu and Wong, 2013)	0.154	0.608			
SLOW6	Maintenance and repair of products (Abdul-Rashid et al., 2017)	0.176	0.633			
SLOW7	Collection of used products from customers for refurbishment or remanufacturing (Lai, Wu and Wong, 2013)	0.171	0.664			

Latent Variable	Item	Item Weight	Item Loading	AVE	Cronbach's α	Composite reliability
SLOW8	Training/support of customers in correct product use (Kjaer et al., 2019)	0.159	0.613			
Closing Practices				0.505	0.800	0.858
CLOS1	Design of products for recycling (Abdul-Rashid et al., 2017)	0.272	0.758			
CLOS2	Use of recycled materials in product designs (Linder, Sarasini and van Loon, 2017)	0.229	0.731			
CLOS3	Design of products to avoid or reduce the use of hazardous or toxic materials (Zhu and Sarkis, 2004)	0.192	0.550			
CLOS4	Collection of used products from customers for recycling Lai, Wu and Wong, 2013)	0.250	0.763			
CLOS5	Recovery of components from used products for reuse in other products (Lai, Wu and Wong, 2013)	0.241	0.767			
CLOS6	Transfer of wastes or by-products for reuse in another process (Masi et al., 2018)	0.217	0.671			
	Narrowing Practices			0.643	0.861	0.900
NAR1	Design of products to reduce the consumption of material/energy during the use phase (Abdul-Rashid et al., 2017)	0.267	0.789			
NAR2	Design of products to reduce their weight (Abdul-Rashid et al., 2017)	0.227	0.737			
NAR3	Re-design of production processes to reduce the	0.243	0.841			

Latent Variable	Item	Item Weight	Item Loading	AVE	Cronbach's α	Composite reliability
	consumption of material/energy (Abdul-Rashid et al., 2017)					
NAR4	Supplier collaboration to reduce the consumption of material/energy (Zhu and Sarkis, 2004)	0.251	0.852			
NAR5	Customer collaboration to reduce the consumption of material/energy (Zhu and Sarkis, 2004)	0.259	0.787			
FS	Lai, Wu and Wong (2013)			0.845	0.820	0.924
FS1	Annual Turnover	0.469	0.897			
FS2	Number of Employees	0.616	0.942			
IEO	Banerjee (2002)			0.753	0.891	0.924
IEO1	At our firm, we make a concerted effort to make every employee understand the importance of environmental preservation.	0.305	0.871			
IEO2	Our firm has a clear policy statement urging environmental awareness in every area.	0.275	0.884			
IEO3	Environmental preservation is a high-priority activity in our firm.	0.302	0.874			
IEO4	Preserving the environment is a central corporate value in our firm.	0.270	0.843			

3.3.3 Data analysis

The analysis applied variance-based structural equation modelling (SEM) to test the hypotheses, specifically the Partial Least Squares (PLS) technique. This technique is suitable for this study due to two reasons: 1) The sample is relatively small (*n* = 206); 2) This study focuses on the prediction of dependent variables. This method was chosen over covariance-based SEM due to the exploratory nature of this research (Hair, Ringle and Sarstedt, 2011).

SmartPLS software was used to analyse the measurement as well as the structural model (Ringle, Wende and Becker, 2015). Using PLS entails a two-stage approach: 1) The assessment of the reliability and validity of the measurement model and; 2) the evaluation of the structural model. The measurement model specifies the indicators and their relationships with the constructs, whereas the structural model includes the latent variables and their relationships which are captured in path coefficients (Hair et al., 2017, p.321).

3.4 Results

3.4.1 Measurement model

Since all constructs are reflective, the measurement model is assessed in four steps: individual item reliability, construct reliability, convergent validity, and discriminant validity (Hair et al., 2017, p.106) (see Table 3-2). Individual item reliability is considered adequate when the item loading exceeds 0.7. There were a number of items (SLOW1, SLOW4-8, CLOS2-3) with indicator loadings below 0.7. Even though this result is not desirable, the decision was made not to remove any indicators to ensure the content validity of the construct (Hair et al., 2017, p.113). According to the procedure described by Hair et al. (2017, p. 133), items with indicator loadings between 0.4 and 0.7 should be considered for removal from the scale only after carefully considering the effects on content validity. Based on a review of the literature, it was decided that removal of these practices would have resulted in an inadequate representation of the SCC concept (Bocken et al., 2016; Kalmykova, Sadagopan and Rosado, 2018). In addition, the decision was also made to keep the items, since weaker loadings are often obtained in

exploratory research with newly developed scales (Hulland, 1999). Internal consistency reliability is evaluated by Cronbach's α and the composite reliability. All Cronbach's α and composite reliability were between the specified threshold of 0.7 and 0.9, thereby supporting the reliability of the constructs. Table 3-3 presents the descriptive statistics of the survey results.

Table 3-3 Descriptive statistics

Variable	Mean	S.D.	Min	Max
PO PSS	3.177	1.160	0	5
UO PSS	1.896	1.433	0	5
RO PSS	2.124	1.477	0	5
Slowing	3.464	0.935	1	5
Closing	3.213	1.008	1	5
Narrowing	3.296	1.101	1	5
IEO	3.939	0.841	1	5

Convergent validity is assessed using the average variance extracted (AVE) measure. Apart from the slowing construct, all AVE values exceeded the minimum threshold of 0.5. The lower AVE of slowing (0.468) is accepted, because it is still close to 0.5 and because the AVE results from the weaker indicator loadings. The discriminant validity was examined using two methods (see Table 3-4): the Fornell and Larcker (1981) criterion and the heterotrait-monotrait (HTMT) ratio (Henseler, Ringle and Sarstedt, 2015). For the HTMT ratio, all variables were below the required 0.85 threshold value (Henseler, Ringle and Sarstedt, 2015). The HTMT ratio was shown to be significantly different from 1 through a bootstrapping procedure with a 95 per cent confidence interval (Hair et al., 2017, p.119). The comparison of the square root of AVE and correlations for pairs of constructs (Fornell and Larcker, 1981), suggest that discriminant validity is achieved.

Table 3-4 Discriminant validity

Heterotrait-monotrait (HTMT) ratio								
	Closing	Firm Size	IEO	Narrowing	PO PSS	RO PSS	Slowing	UO PSS
Closing								
Firm Size	0.2							
IEO	0.451	0.056						

Narrowing	0.543	0.33	0.395					
PO PSS	0.313	0.221	0.303	0.415				
RO PSS	0.308	0.062	0.267	0.259	0.239			
Slowing	0.559	0.235	0.407	0.589	0.582	0.327		
UO PSS	0.335	0.062	0.168	0.279	0.373	0.549	0.373	

Fornell-Larcker Criterion

	Closing	Firm Size	IEO	Narrowing	PO PSS	RO PSS	Slowing	UO PSS
Closing	0.711							
Firm Size	0.2	0.919						
Internal EO	0.451	0.056	0.868					
Narrowing	0.543	0.33	0.395	0.802				
PO PSS	0.313	0.221	0.303	0.415	0.781			
RO PSS	0.308	0.062	0.267	0.259	0.239	0.9		
Slowing	0.559	0.235	0.407	0.589	0.582	0.327	0.684	
UO PSS	0.335	0.062	0.168	0.279	0.373	0.549	0.373	0.849

To further validate the measurement model, the potential for common method bias was addressed in two ways. Firstly, the Harman single-factor test was used to check for this possibility. According to the unrotated factor solution, the first factor accounts for 30.982 per cent of the variance, which indicates that no factor accounts for the majority of covariance among the measures. Due to the potential weakness of the Harman single-factor test in addressing common method variance (Podsakoff et al., 2003), a second test was conducted. A full collinearity assessment was conducted employing the Partial Least Squares method (Kock, 2015). The VIFs for all variables ranged between 1.179 and 2.226, well below the 3.3 threshold. Thus, these two tests imply that the findings have not been affected by the use of the same data source, i.e. common method bias was absent. The results of the quality checks of the measurement model were satisfactory and the analysis therefore continued with the structural model to test the hypotheses developed in Section 2.

3.4.2 Structural model

Bootstrapping (5,000 samples) was used to generate standard errors and *p*-values, to determine the statistical significance of the path coefficients. To check for collinearity issues, the variance inflation factors (VIFs) were generated for all latent variables in the software. As previously mentioned, all VIF values were

below the 3.3 threshold (Kock, 2015). Therefore, collinearity among the constructs was not a critical issue in the structural model. The explanatory power of the structural model was examined through the coefficient of determination (R^2).

The results showed that slowing and closing had substantial R^2 values of 0.43 and 0.31, whereas the prediction of narrowing was slightly weaker (R^2 = 0.267) (Hair et al., 2017, p.199). Blindfolding was used to evaluate the model with the cross-validated redundancy index Q^2 for the endogenous variables. Q^2 values greater than 0.02 imply that the model has predictive relevance (Chin, Marcolin and Newsted, 2003). Slowing had the highest (0.203) followed by narrowing (0.173) and finally closing (0.158). The results confirm that the structural model has satisfactory predictive relevance for all the endogenous constructs.

In Table 3-5, Model 1 includes the main direct paths, between the different PSSs and the three dimensions of SCC practices. In this scenario, the results support H1, H2b, H3a-c, but not H2a. Model 2 introduces the assumed moderating effects of firm size and internal environmental orientation. As in regression analysis, the predictor and moderator variables are multiplied to obtain the interaction terms. The evaluation of H4 and H5 employs the two-stage technique, which is generally recommended for modelling the interaction term (Hair et al., 2017, p.255).

Table 3-5 Structural model

Relationships	**Model 1**		**Model 2**		**f2**	**Support**
	R^2 (adj.)	Q^2	R^2 (adj.)	Q^2		
	R^2_{Slow} = 0.375	Q^2_{Slow} = 0.172	R^2_{Slow} = 0.430	Q^2_{Slow} = 0.203		
	R^2_{Clos} = 0.147	Q^2_{Clos} = 0.067	R^2_{Clos} =0.308	Q^2_{Clos} = 0.158		
	R^2_{Narr} = 0.075	Q^2_{Narr} = 0.049	R^2_{Narr} =0.267	Q^2_{Narr} = 0.173		
	Path Coeff.	*Conf. Interval*	*Path Coeff.*	*Conf. Interval*		
H1: PO-SLO	0.510***	(0.40;0.63)	0.413***	(0.29; 0.55)		Yes

Relationships	Model 1		Model 2		f2	Support
H2a: UO-SLO	0.105^{ns}	(-0.03; 0.24)	0.116^{ns}	(-0.03; 0.28)		No
H2b: UO-CLO	0.266***	(0.13; 0.42)	0.243**	(0.10; 0.41)		Yes
H3a: RO-SLO	0.146*	(0.02; 0.27)	0.121^{ns}	(-0.04; 0.27)		Yes
H3b: RO-CLO	0.179*	(0.01; 0.35)	0.072^{ns}	(-0.10; 0.41)		Yes
H3c: RO-NAR	0.282***	(0.16; 0.42)	0.173**	(0.03; 0.30)		Yes
H4: FS						No
FSxPO-SLO			0.043^{ns}	(-0.08; 0.17)	0.014	
FSxUO-SLO			-0.08^{ns}	(-0.22; 0.06)	0.003	
FSxUO-CLO			-0.003^{ns}	(-0.12; 0.12)	0.011	
FSxRO-SLO			-0.068^{ns}	(-0.21; 0.07)	0.015	
FSxRO-CLO			-0.033^{ns}	(-0.16; 0.10)	0.001	
FSxRO-NAR			-0.057^{ns}	(-0.18; 0.06)	0.012	
H5: IEO						No
IEOxPO-SLO			-0.080^{ns}	(-0.18; 0.02)	0.003	
IEOxUO-SLO			0.053^{ns}	(-0.10; 0.10)	0.007	
IEOxUO-CLO			-0.100^{ns}	(-0.25; 0.52)	0	
IEOxRO-SLO			-0.129^{ns}	(-0.29; 0.03)	0.005	
IEOxRO-CLO			-0.034^{ns}	(-0.17; 0.11)	0.001	
IEOxRO-NAR			-0.090^{ns}	(-0.19; 0.04)	0.005	

Relationships	Model 1	Model 2	f2	Support

Notes: PO: Product-oriented PSS; UO: Use-oriented; RO: Result-oriented; SLO: Slowing; CLO: Closing; NAR: Narrowing; FS: Firm Size; IEO: Internal Environmental Orientation. ***p < 0.001; **p < 0.01: *p < 0.05; ^{ns}: not significant

The moderator analysis for firm size and internal environmental orientation is included in both Model 2 of Table 3-5 as well as in the two-way interaction analysis graphs of Figure 3-2 and Figure 3-3. Figure 3-2 shows the two-way interaction analysis graph for the moderation effects of firm size. The relationship between product-oriented PSSs and slowing (i), appears to be the only relationship where firm size has a positive moderation effect, while it appears to have a slightly negative moderating effect on the other relationships. Nevertheless, the bootstrapping analysis from Table 3-5 showed that none of these moderation effects are significant. Consequently, H4(a-c) are not supported.

Figure 3-2 Two-way interaction analysis graph for moderating effect of firm size

Notes: PO: Product-oriented PSS; UO: Use-oriented; RO: Result-oriented; SLO: Slowing; CLO: Closing; NAR: Narrowing; FS: Firm Size; IEO: Internal Environmental Orientation.

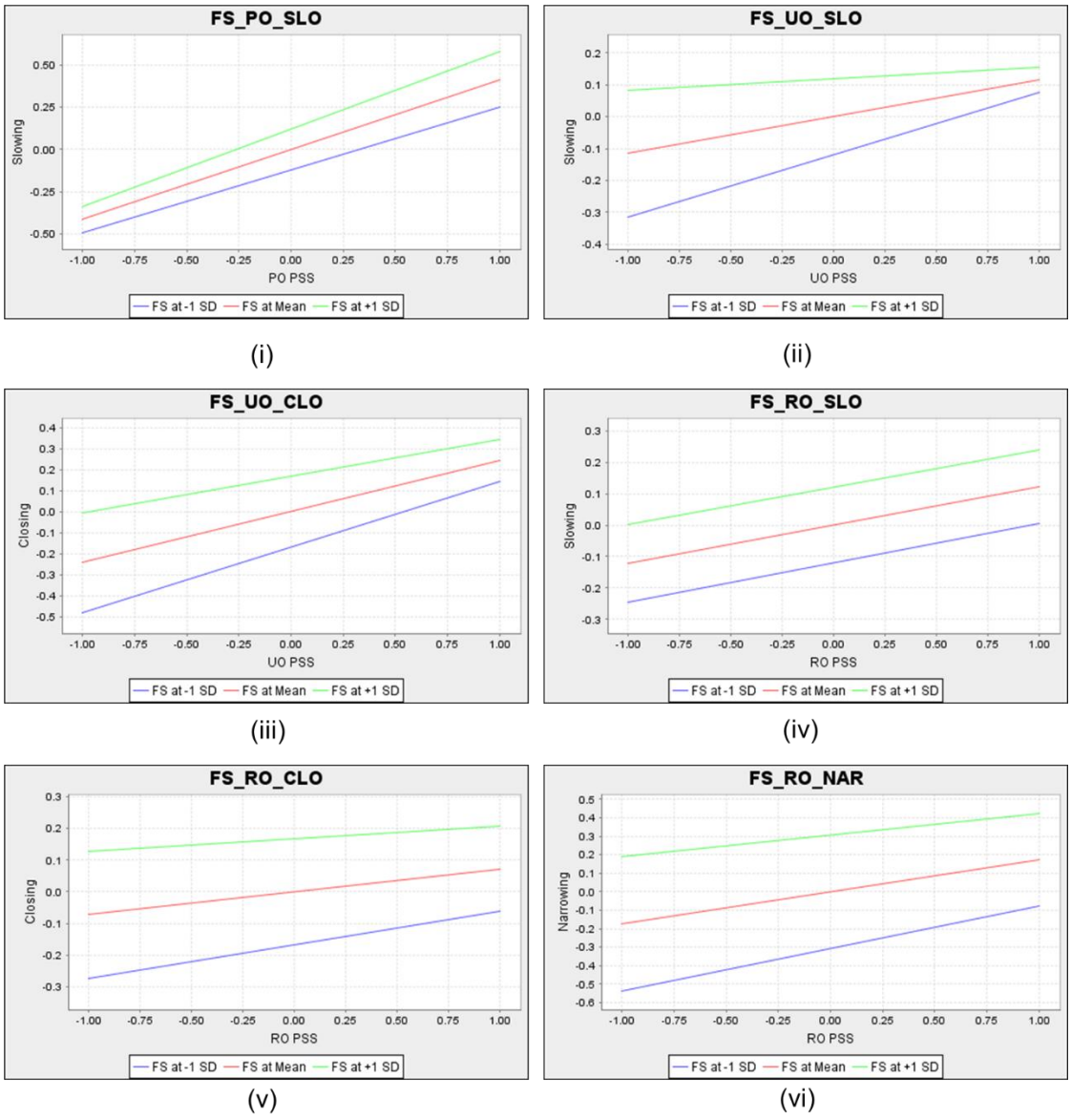
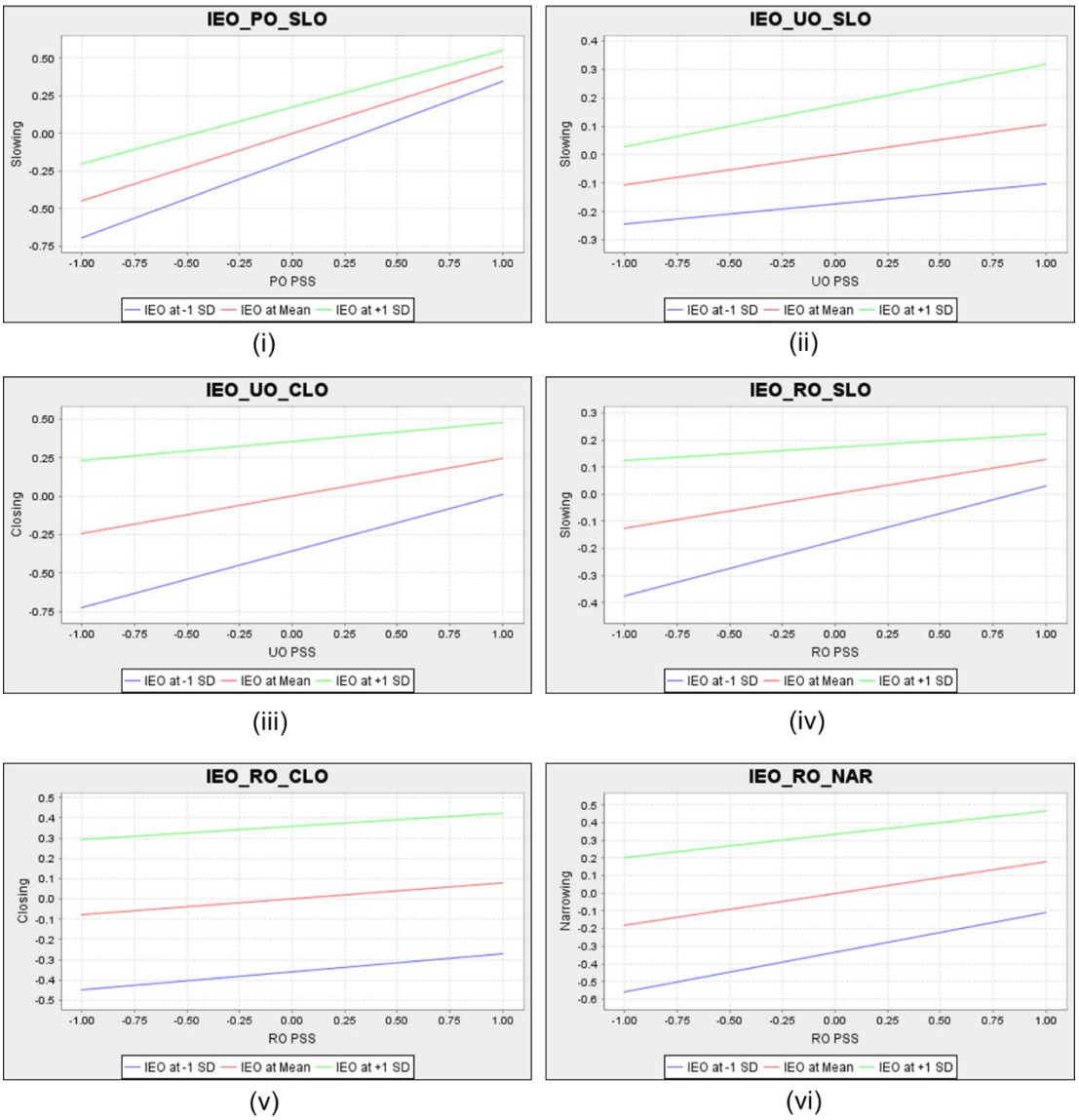


Figure 3-3 on the other hand depicts the two-way interaction analysis graph for the moderation effects of internal environmental orientation. The only slightly positive moderation effect appears to be between use-oriented PSSs and slowing (ii), while it appears that internal environmental orientation has a negative moderating effect on the other relationships. Similar to the previous hypothesis, the bootstrapping analysis from Table 3-5 showed that none of these moderation effects are significant. Consequently, H5(a-c) are not supported.

Figure 3-3 Two-way interaction analysis graph for moderating effect of internal environmental orientation

Notes: PO: Product-oriented PSS; UO: Use-oriented; RO: Result-oriented; SLO: Slowing; CLO: Closing; NAR: Narrowing; FS: Firm Size; IEO: Internal Environmental Orientation.



3.5 Discussion and conclusions

Rooted in the natural resource-based view (NRBV) of the firm (Hart, 1995), this study reveals whether and how PSSs impact the implementation of SCC practices in UK equipment and machinery manufacturing firms. The findings show that: 1) PSSs contribute positively to SCC practice implementation; 2) Firm size and internal environmental orientation do not moderate the relationship

between PSSs and SCC practice implementation; 3) The newly developed measurement items are a suitable tool for measuring SCC practice implementation. These results offer a series of theoretical and managerial implications that are analysed below.

3.5.1 Theoretical implications

This study makes three key contributions to the literature: Firstly, in regard to the first research question ("What impact do PSSs have on the implementation of SCC practices?") it shows that the assumed contribution (Hofmann, 2019; Kühl et al., 2019; Tukker, 2015; Yang et al., 2018) also hold in traditional manufacturing firms. This is relevant because prior studies have focused mostly on sustainability-oriented start-ups (Matschewsky, 2019). The findings show a positive relationship for the contribution of product-oriented PSSs to a slowing of resource loops (H1), use-oriented PSSs to a closing of resource loops (H2b) as well as the contribution of result-oriented PSSs to the slowing (H3a), closing (H3b), and narrowing of resource loops (H3c). The high path coefficient of product-oriented PSSs compared to use- and result-oriented PSSs contradicts the theory and previous empirical evidence (Hofmann, 2019; Kühl et al., 2019; Tukker, 2015; Yang et al., 2018). This surprising finding can be explained by the fact that these services had higher implementation rates compared to use- and result-oriented PSSs (see Table 3-3). In servitization, manufacturers typically start with offering product-oriented PSSs to build and improve their service capabilities before expanding into more complex service offerings, such as use- and result-oriented PSSs (Sousa and da Silveira, 2017).

Secondly, the findings provide empirical evidence for an emerging theoretical argument on the fallacy of PSSs' contribution to SCC (Hofmann, 2019; Mayers, Davis and Wassenhove, 2021). The unsupported hypothesis H2a shows that, in practice, use-oriented PSSs are not designed to slow resource loops through product life extension (Hofmann, 2019; Mayers, Davis and Wassenhove, 2021). Overall, the findings suggest that PSS design and implementation are currently not optimised for SCC potential and that more design or policy support are needed (e.g., incentive setting through carbon or resource tax) (Calisto Friant,

Vermeulen and Salomone, 2020; Matschewsky, 2019; Zeeuw van der Laan and Aurisicchio, 2020).

Thirdly, the study contributes to the conceptual understanding of SCC by developing a measurement scale and items based on the classification of slowing, closing, and narrowing of resource loops (Bocken et al., 2016; Geissdoerfer et al., 2017). It extends previous conceptualisations (Masi et al., 2018; Zhu, Geng and Lai, 2010) in two ways. Firstly, it aligns the construct with the theoretical dimensions of SCC instead of adopting dimensions and items that were developed for other sustainable supply chain narratives. This is important for the content validity of the construct since these narratives are related, but different (Batista et al., 2018). Secondly, it provides a more robust classification of practices than Masi et al. (2018), by establishing the construct's validity and reliability. The results indicate good indicator loadings for the practices associated with narrowing but suggest that adapting the items associated with slowing and closing may help improve some of the weaker outer loadings (<0.70). These dimensions and measurement items contribute to theory by providing a better understanding of SCC practice implementation in organisations.

Fourthly, it also elaborates on critical success factors for SCC implementation in manufacturing firms (Dey et al., 2020). Regarding the second research question ("Does firm size moderate the relationship between PSSs and SCC practice implementation?), the research shows that firm size does not moderate the relationship between PSSs and SCC practice implementation (H4a-c). This shows that smaller firms are not at a disadvantage in respect to implementing SCC practices. One explanation for the insignificance of firm size is that smaller firms may have a higher capacity to learn, develop new knowledge and embrace new ideas, such as CE (Leal-Rodríguez et al., 2015). Empirically, this is supported by the examples of SMEs and start-ups experimenting with circular business models (Corvellec and Stål, 2017; Linder and Williander, 2017).

Regarding the third research question ("Does internal environmental orientation moderate the relationship between PSSs and SCC practice implementation?), the research shows that internal environmental orientation does also not

moderate the relationship between PSSs and SCC practice implementation (H5a-c). This counters previous results that highlighted the importance of a pro-environmental corporate culture in enabling SCC practice implementation (Kühl et al., 2019; Rizos et al., 2016). This can be explained by that fact that SCC practice implementation is likely to be ultimately determined by more pragmatic reasons, such as cost reduction or competitiveness benefits (Dey et al., 2019, 2020). In particular, manufacturing firms implement these practices if they result in economic benefits, such as cost reduction (Dey et al., 2019, 2020). This work therefore supports previous work (Matschewsky, 2019), which argues that there is potential in PSS contributing to mainstream improvement of traditional manufacturing firms.

3.5.2 Managerial and policy implications

Firstly, the findings suggest that current versions of PSSs do not maximise the SCC potential. This study contributes to the CE literature, by developing and testing a benchmarking tool that can be used by practitioners with a conceptual framework of a 19-item measurement scale, evaluating the different elements of SCC practices implementation. Managers in manufacturing firms can use this validated scale as a self-diagnostic tool to assess their current performance in the transition to SCC and to identify specific areas for improvement.

Secondly, this study provides practitioners as well as policy-makers relevant empirical evidence about the limitations of PSSs. It highlights the potential limitations of use-oriented PSSs in the slowing of resource loops. For practitioners, it shows that design guides are needed to support the circular design and implementation of business models. This study highlights these efforts with the previously mentioned benchmarking tool. For policymakers, it shows that enabling business models by itself will not necessarily lead to the desired economic and environmental win-wins (Calisto Friant, Vermeulen and Salomone, 2020), but that deeper reforms are needed to support SCC practice implementation, such as reduced taxes on services or the introduction of ambitious resource or carbon taxes.

3.5.3 Limitations and further research

This study has several limitations, which suggest opportunities for further research. Firstly, it relies on the perceptions of survey respondents. To elicit their insights, the survey methodology employs a single method. Future research could adopt a longitudinal data analysis method to spot potential developments in the SCC practice implementation, particularly as firms innovate their PSSs. This could be supported by the development of objective measures for PSSs and SCC practice implementation to supplement the subjective assessment of the relevant constructs. Secondly, due to the exploratory nature of this study, the data was acquired using a volunteer opt-in panel. Future research should adopt probability sampling techniques to increase the generalisability of the findings.

Thirdly, this research is focused on a specific set of industries (equipment and machinery manufacturing) in a set geographical context (UK). As a result, care must be taken when generalising the results to other contexts and geographic locations. As we provide both the measurement items and the survey sample selection rationale along with methodological choices in modelling, we deem other researchers can easily replicate our findings with new data. For example, further studies might be carried out with larger samples to explore differences between groups of firms, for example, among micro-, small-, and medium-sized firms or include additional control variables (e.g. industry sector) to help rule out confounding effects and to further improve the robustness of the results. The findings from this study also point to the potential shortcomings of use-oriented PSSs in slowing resource loops. The literature on the potential limitations of PSSs is just emerging and to date, it is primarily based on theoretical arguments (Hofmann, 2019). Case study research is needed to explore the shortcomings of PSSs in more detail.

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4 Supply chain circularity implications of product-service systems: A multi-case study (Paper 3)

Abstract

Using the Natural Resource-Based View (NRBV) as a theoretical lens, this paper investigates and elaborates on the assumption that product-service systems (PSSs) contribute to supply chain circularity (SCC) by slowing and closing resource loops. A case study methodology is applied across three manufacturing firms located in the UK and Germany. They provide different PSSs for personal computers, power tools, and wind turbines. Multiple sources of evidence were triangulated to improve construct validity, including 19 semi-structured interviews, company documents, and quantitative data. The research shows that in comparison to product-oriented PSSs, use-oriented and result-oriented PSSs do not necessarily contribute to the slowing and closing of resource loops. It also provides empirical evidence for nineteen enablers and barriers and how they affect the contribution of different PSS types to the slowing and closing of resource loops. These contextual factors are categorised into organisational, financial, technology and knowledge, market, supply chain, and regulatory factors. This paper makes three key contributions: Firstly, it shows that SCC outcomes are not only dependent on the PSS type, but also on the presence of enablers and barriers in the firm context. Secondly, it induces four propositions that highlight the enabling and inhibiting effect of contextual factors. Chief among these are organisational factors that affect the contribution of use-oriented PSSs to the slowing of resource loops through refurbishment. Thirdly, it develops an empirically validated conceptual framework that extends knowledge, by accounting for the effect of contextual factors on the contribution of the different PSSs on the slowing and closing of resource loops.

Keywords Circular economy, product-service system, supply chain management, servitization, case study

4.1 Introduction

In recent years, the circular economy (CE) concept has attracted increasing interest from policy-makers, business representatives, and academics as an approach to decouple economic growth from environmental impacts (Hofmann, 2019; Kjaer et al., 2019). The CE agenda highlights the importance of transitioning from linear 'take-make-dispose' to circular supply chains (Batista et al., 2018). Circular supply chains slow, close, and narrow resource loops to increase competitive advantage as well as economic, environmental, and operational performance (Geissdoerfer et al., 2017, 2018).

The CE concept proposes that manufacturing firms should innovate their business models from selling products to providing services (Ellen MacArthur Foundation, 2013; Lacy and Rutqvist, 2015). These types of business models are called product-service systems (PSSs) (Tukker, 2004). An example is Rolls-Royce's "Power-by-the-hour" service, in which the manufacturer is not paid according to the conducted service activities (e.g. repairs), but rather based on the outcome of the activities (i.e. the number of hours the engine is in the air) (Ng, Ding and Yip, 2013). In the CE literature, it is argued that PSSs contribute to higher levels of supply chain circularity (SCC) (Ellen MacArthur Foundation, 2013; Lacy and Rutqvist, 2015; Yang et al., 2018). This positive relationship between PSS and SCC can be explained by the tenets of the Natural Resource-Based View (NRBV) (Hart, 1995). When manufacturers take over responsibility for product functionality or outcome, the role of the product changes from consumable to capital asset (Hofmann, 2019; Tukker, 2015). As a result, manufacturers will increase SCC to minimise the costs and resources required to deliver PSS (Matschewsky, 2019; Rosa, Sassanelli and Terzi, 2019; Tukker, 2015).

To date, the argument for the contribution of PSSs to SCC is primarily of a theoretical or conceptual nature (Reim, Parida and Örtqvist, 2015; Tukker, 2004, 2015; Vezzoli et al., 2015). Initial empirical research on the contribution of PSSs to SCC typically focuses on niche start-ups with a distinct sustainability or circularity strategy (Corvellec and Stål, 2017; Manninen et al., 2018; Sousa-

Zomer et al., 2018a). There is very limited empirical evidence from traditional manufacturing firms that pursue PSSs for economic and commercial and not for environmental reasons (Matschewsky, 2019; Yang et al., 2018). Even though Matschewsky (2019) offered initial insights into the contribution of PSSs in traditional manufacturing firms, further gaps remain. In particular, there is an opportunity to contribute empirical evidence to an emerging theoretical argument questioning the contribution of PSSs to a slowing of resource loops (Hofmann, 2019) as well as an understanding of the PSS factors that close resource loops (Zeeuw van der Laan and Aurisicchio, 2020).

Moreover, a research gap remains on the role of contextual factors in determining a PSS's contribution to SCC (Kühl et al., 2019; Lüdeke-Freund, Gold and Bocken, 2019). Previous empirical studies on this phenomenon have not investigated these in detail. Apart from a few exceptions (Sousa-Zomer et al., 2018b; Vermunt et al., 2019), the literature on enablers and barriers for SCC do not focus specifically on PSSs (Guldmann and Huulgaard, 2020; Tura et al., 2019). This study therefore aims to investigate and elaborate on the relationship between PSSs and SCC by answering the following research questions:

1) How do PSSs contribute to SCC?
2) What internal and external contextual factors enable or inhibit the contribution of PSSs to SCC?

The research questions are examined through the lens of the NRBV (Hart, 1995) using three case studies in manufacturing industries. This theory-testing case study makes three key contributions:

- Firstly, it shows that SCC outcomes are not only dependent on the PSS type, but also on the presence of enablers and barriers in the firm context.
- Secondly, it induces four propositions that highlight the enabling and inhibiting effect of contextual factors. Chief among these are organisational factors that affect the contribution of use-oriented PSSs to the slowing of resource loops through refurbishment.

- Thirdly, it develops an empirically validated conceptual framework that extends knowledge, by accounting for the effect of contextual factors on the contribution of the different PSSs on the slowing and closing of resource loops.

This paper is structured as follows: Section 4.2 reviews the literature on PSSs, SCC, the conceptual framework, and the NRBV; Section 0 explains the research methodology; Section 4.4 presents the findings; Section 0 develops propositions and discusses the empirically validated framework; Section 4.6 presents the theoretical and practical contributions, as well as the limitations and future research directions.

4.2 Literature Review

4.2.1 Classifying PSSs

PSSs are defined as “tangible products and intangible services designed and combined so that they jointly are capable of fulfilling specific customer needs” (Tukker, 2004, p.246). There are three types of PSSs: product-oriented, use-oriented, and result-oriented (Tukker, 2004). In product-oriented PSSs, the product is sold to the customer and enhanced by product-related services, such as maintenance or extended warranty agreements (Gaiardelli et al., 2014; Tukker, 2004). Use-oriented PSSs provide functionality or access, for example, through leasing, renting, or sharing instead of selling products (Gaiardelli et al., 2014; Tukker, 2004). The manufacturer owns and services the product, while the customer pays a fee for using it (Gaiardelli et al., 2014; Tukker, 2004). Result-oriented PSSs deliver a function or pre-determined result, such as availability or performance (Gaiardelli et al., 2014; Tukker, 2004). PSSs can be described along seven characteristics (Gaiardelli et al., 2014):

- **Product owner:** This clarifies which party owns the product during its use-phase (Tukker, 2004). According to the PSS classification, the customer owns the product in product-oriented PSSs, whereas the manufacturer retains product ownership in use- and result-oriented PSSs (Gaiardelli et al., 2014; Tukker, 2004).

- **Product user:** This category describes whether the product is used by the customer or the manufacturer during the use phase (Gaiardelli et al., 2014). In product- and use-oriented PSSs, the customer is the product user, whereas in result-oriented PSSs both the customer or the manufacturer can be the product user (Gaiardelli et al., 2014).
- **Product decision-maker:** This clarifies which party decides when and how to manage the product, for example by controlling maintenance activities (Gaiardelli et al., 2014; Matschewsky, 2019). Similar to product use, product decision-making lies with the customer in product-oriented and use-oriented PSSs, whereas in result-oriented PSSs it can be either with the customer or the manufacturer, depending on the offering (Gaiardelli et al., 2014).
- **Customisation:** In PSSs, product or service customisation is aimed at meet specific customer needs (Mourtzis et al., 2018; Song and Sakao, 2017). According to the classification, customisation can be either high or low (Gaiardelli et al., 2014). Product-oriented PSSs are standardised offerings that do not integrate specific customer needs and therefore have a low degree of customisation (Reim, Parida and Örtqvist, 2015). In use-oriented PSSs, customisation can be either low or high and is expected to increase with the size of the customer and the contract (Reim, Parida and Örtqvist, 2015). Result-oriented PSSs have high degrees of customisation, since they require to meet specific customer needs (Gaiardelli et al., 2014; Reim, Parida and Örtqvist, 2015; Smith, Maull and Ng, 2014).
- **Relationship intensity:** Relationship intensity refers to the involvement and commitment of both the manufacturer and the customer (Gaiardelli et al., 2014; Mathieu, 2001). It manifests itself in the frequency and quality of information sharing as well as operational linkages (Bastl et al., 2012). Examples of operational linkages are common software platforms to exchange information or facilitate operations (Baines and Lightfoot, 2013; Bastl et al., 2012) or jointly carrying out service activities (Smith, Maull and Ng, 2014). In product-oriented PSSs, the relationship intensity is low

(Reim, Parida and Örtqvist, 2015). In use-oriented and especially in result-oriented PSSs, the relationship intensity is high so that the manufacturer can gain insight into customer needs (Reim, Parida and Örtqvist, 2015). In result-oriented PSSs, this intensity can manifest itself in deploying staff within customer operations or by linking information and communication technologies to optimise service operations (Baines and Lightfoot, 2013).

- **Risk:** This category describes whether the risk associated with the PSS is borne by the manufacturer or the customer (Gaiardelli et al., 2014). In PSSs, a manufacturer can internalise technical risks, such as unexpected breakdowns, behavioural risks, such as customers misusing products, or delivery competence risks, such as an inability to provide a promised result (Reim, Parida and Sjödin, 2016). In product-oriented PSSs, the customer bears the risks associated with the product, such as downtime (Gaiardelli, Martinez and Cavalieri, 2015). In use-oriented PSSs, the manufacturer internalises technical and behavioural risks of the customer, since they are responsible for the functionality of the product (Reim, Parida and Örtqvist, 2015). In result-oriented PSSs, the manufacturer internalises risks associated with technical breakdowns, their own delivery competence risks as well as the customer's behaviour (Reim, Parida and Örtqvist, 2015; Reim, Parida and Sjödin, 2016).
- **Payment model:** The payment model describes the basis on which customers pay for the PSS (Lay, Schroeter and Biege, 2009). In product-oriented PSSs, customers pay a mark-up or fixed rate for the equipment and the additional service. In use-oriented PSSs, customers pay depending on the product usage (Gaiardelli et al., 2014). In result-oriented PSSs, payment mechanisms are based on performance or results and can include pay-per-result or pay-for-availability (Gaiardelli et al., 2014; Lay, Schroeter and Biege, 2009).

4.2.2 Assessing SCC

Circular supply chains slow, close, and narrow resource loops to increase competitive advantage as well as economic, environmental, and operational

performance (Geissdoerfer et al., 2018). The slowing principle focuses on preserving the value of products for example by designing products for durability and repairability, by conducting maintenance or by refurbishing/remanufacturing products (Bocken et al., 2016). The closing principle focuses on returning resources from post-use to production (Bocken et al., 2016). Narrowing aims at reducing the amount of material and energy inputs per manufactured product (Bocken et al., 2016). While slowing and closing are unique to the CE concept, the narrowing of resource loops also fits into the resource efficiency narrative of the linear economy (Bocken et al., 2016; Lüdeke-Freund, Gold and Bocken, 2019). As a result, this study will focus on the slowing and closing of resource loops, because these are the most relevant modes of value creation in a CE (Bocken et al., 2016; Hofmann, 2019).

Different methods exist for assessing SCC. Traditionally, material flow analysis (MFA) and lifecycle assessment (LCA) are used (Elia, Gnoni and Tornese, 2017). Nevertheless, MFA provides information about the quantity of resource flows, but not their quality, while LCAs are often hindered by poor data availability and methodological complexity (Elia, Gnoni and Tornese, 2017). Another option is the Material Circularity Indicator (Ellen MacArthur Foundation, 2015), which, however, does not differentiate between the type of product recovery (e.g. repair or refurbishment).

One promising approach for assessing the slowing and closing of resource loops are the metrics developed by Figge et al. (2018). They are based on two indicators for assessing the slowing (longevity) and closing (circularity) of resource loops. The slowing is expressed in a unit of time (e.g. months or years), while closing is expressed in the number of times a resource is used (Figge et al., 2018). Compared to other methods, these metrics are aligned well with the slowing and closing concepts of SCC and provide an assessment method at the firm level. The outcome for both indicators depends on the initial use/lifetime, refurbishment, and recycling. Each indicator is comprised of three phases: the initial use, refurbishment, and recycling phase. These are defined as follows:

- **Initial lifetime/use:** The initial lifetime of the product is measured in the years or months that a product is used in its first lifecycle.
- **Refurbishment contribution:** The additional lifetime and resource loop closure contribution from refurbishment or remanufacturing and subsequent reuse of products. It depends on the number of products that are returned, the fraction of products that are refurbished, the number of subsequent lifecycles as well as their duration.
- **Recycling contribution:** This is the contribution of recycling-related activities to the slowing and closing of resource loops. The original indicator assumes a closed-loop in which materials are recycled and reused within the same system. Nevertheless, in many cases, there is an open-loop system, in which recycled materials are used in a different context. In such a case, the recycling contribution depends on the use of recycled materials in the product as well as the amount of material recycled at end-of-life. In such a case, no claims can be made about the contribution to slowing, because it is unclear what the recycled materials are used for.

4.2.3 Conceptual map

This research further examines the conceptual map that was developed from a previous systematic literature review (see Figure 4-1) (Kühl et al., 2019). The vertical axis represents the degree of SCC, the degree to which resource loops are slowed and closed. The horizontal axis represents different PSS types. It hypothesises that the contribution of use-oriented and result-oriented PSSs to SCC is higher than for product-oriented PSSs. The comparison of these types of PSSs is motivated by the fact that product-oriented PSSs still focus on selling products, whereas use-oriented and result-oriented PSSs deliver services (Tukker, 2015). This makes it possible to test the assumption that providing services results in higher SCC outcomes compared to selling products (Ellen MacArthur Foundation, 2013; Hofmann, 2019; Lacy and Rutqvist, 2015).

The conceptual map postulates that internal and external contextual factors enable and inhibit the contribution of PSSs to SCC. At present, the literature on the role of contextual factors is still emerging (Kühl et al., 2019). In the CE literature, a range of generic frameworks of drivers, enablers and barriers are identified for businesses (Govindan and Hasanagic, 2018; Guldmann and Huulgaard, 2020; Kirchherr et al., 2018; Rizos et al., 2016; Tura et al., 2019; Vermunt et al., 2019). Nevertheless, these frameworks do not distinguish either between PSS types, or between slowing and closing outcomes. As a result, no hypotheses could be developed for enablers and barriers. A review of potential internal and external enablers and barriers is presented in Section 4.2.3.2.

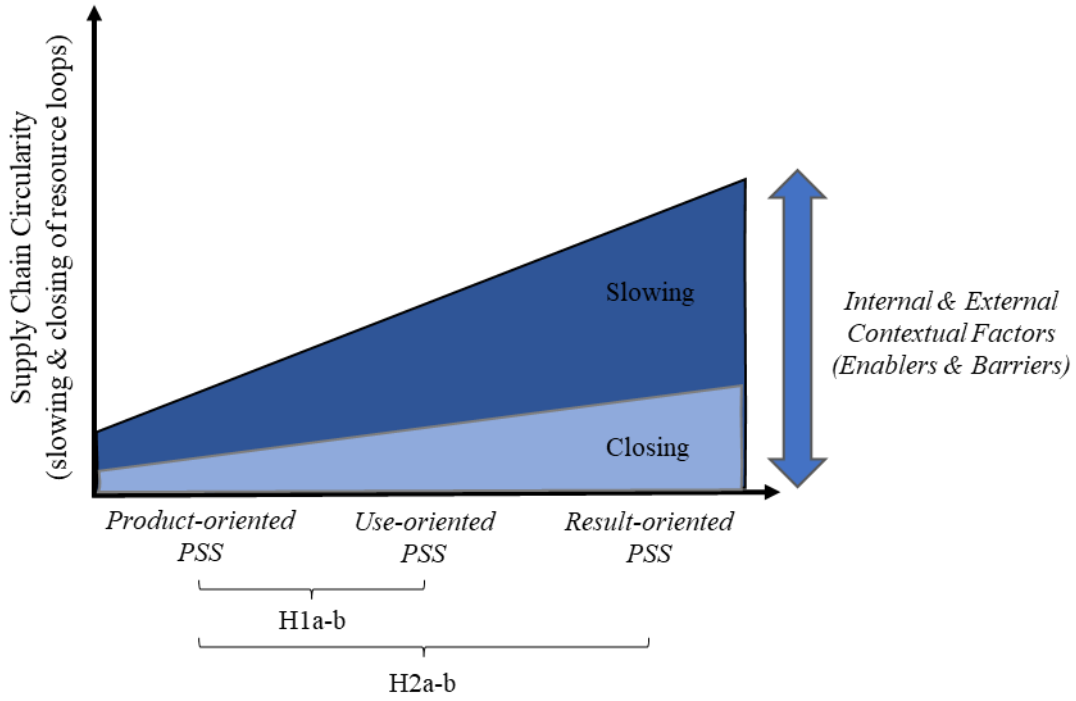

Figure 4-1 Conceptual map adapted from (Kühl et al., 2019)

4.2.3.1 PSSs and SCC

The hypotheses underlying the conceptual map are rooted in the resource-based view (RBV) of the firm and its sustainability-oriented variant the natural resource-based view (NRBV) (Hart, 1995). The central tenet underlying these theories is that competitive advantage is a result of the valuable, rare, imperfectly imitable, and non-substitutable resources (i.e. called VRIN resources) that a firm owns or

controls (Barney, 1991). The NRBV argues that the original resource-based view (Barney, 1991) did not consider the impact of the natural environment on the firm. To build a sustainable competitive advantage, firms would need to innovate beyond current economic and organisational practices. One of the ways in which firms can create sustainable competitive advantage is through product stewardship, which similar to SCC encompasses the entire product lifecycle and also focuses on practices, such as reverse logistics (Hart, 1995; Vachon and Klassen, 2008). In this strategy, the VRIN resource resulting in sustainable competitive advantage is stakeholder integration, since the implementation of practices, such as reverse logistics, relies on information and knowledge exchange between stakeholders (Hart, 1995; Vachon and Klassen, 2008).

This argument is the foundation for the deduction of the hypotheses in this section. The PSSs contribute differently to SCC, due to their varying degrees of manufacturer-customer integration. PSS types with high degrees of manufacturer-customer integration can implement more SCC practices, since the responsibility of manufacturers for activities across the product lifecycle and the information and knowledge exchange between manufacturer and customer increases (Matschewsky, 2019; Östlin, Sundin and Björkman, 2008). Therefore, the manufacturer has the responsibility and incentive to implement SCC practices, especially when these create economic value (Matschewsky, 2019; Yang et al., 2018; Yang and Evans, 2019).

From the perspective of the NRBV, product-oriented PSSs have the lowest potential for SCC contribution, because they have the lowest degree of manufacturer-customer integration (Gaiardelli et al., 2014). Since the manufacturer is focused on selling products, it profits from shortening lifetimes (i.e. product obsolescence) and high service costs (Matschewsky, 2019; Tukker, 2015). In regard to the closing of resource loops, the manufacturer does not have influence over the product at the end-of-life, because product ownership and disposal responsibility rests with the customer (Gaiardelli et al., 2014). In use-oriented PSSs, however, the manufacturer retains product ownership, which results in a closer integration with the customer's use of the product. As a result,

the manufacturer optimises maintenance and service activities to extend the product life and ultimately reduce the costs of delivering the PSS (Matschewsky, 2019). Since the manufacturer retains ownership in use-oriented PSSs, it has access to information on the timing, location, quantity, and quality of products, which facilitates resource loop closure (Östlin, Sundin and Björkman, 2008). This argument leads to the following hypothesis:

H1a: The slowing of resource loops in use-oriented PSSs is higher than in product-oriented PSSs.

H1b: The closing of resource loops in use-oriented PSSs is higher than in product-oriented PSSs.

From the perspective of the NRBV, result-oriented PSSs have a higher potential for SCC than product-oriented PSSs, because they have a higher degree of manufacturer-customer integration (Gaiardelli et al., 2014). Since the manufacturer is responsible for delivering pre-determined outcomes in result-oriented PSSs, all products and parts used to deliver results become cost centres (Tukker, 2015). In regard to slowing, this means that the manufacturer innovates to minimise the resources used and costs to deliver the outcome (Yang and Evans, 2019). This can include, for example, optimised product design, condition-based maintenance activities to prevent product breakdowns (Baines and Lightfoot, 2013). In regard to closing, the manufacturer also typically retains product ownership in result-oriented PSSs, which does not occur in product-oriented PSSs. This ownership retention facilitates the planning and execution of product returns (Östlin, Sundin and Björkman, 2008). In some variants of result-oriented PSSs, the manufacturer also has control over the product use phase, which provides additional opportunities for resource loop closure, such as cascading waste and by-products (Yang et al., 2018). This argument leads to the following hypothesis:

H2a: The slowing of resource loops in result-oriented PSSs is higher than in product-oriented PSSs.

H2b: The closing of resource loops in result-oriented PSSs is higher than in product-oriented PSSs.

4.2.3.2 Contextual Factors

As depicted in Figure 4-1, the conceptual map postulates that contextual factors enable and inhibit the contribution of PSSs to SCC. An initial list of the categories of contextual factors was developed through a systematic literature review (Kühl et al., 2019) and included: 1) Economic attractiveness of SCC; 2) Firm sustainability strategy; 3) Policy and societal environment; 4) Product category; 5) Supply chain relationships; 6) Technology. Since its publication, new categories of contextual factors for SCC emerged, which were content-wise closely related to the original classification, but formulated more comprehensively (Tura et al., 2019; Vermunt et al., 2019). As a result, the classification of contextual factors was updated to these new categories: 1) Organisational; 2) Financial; 3) Technology and Knowledge; 4) Market; 5) Supply chain; 6) Regulatory. An overview of the expected internal and external contextual factors is presented in Table 4-1.

Internal contextual factors

A pro-environmental organisational culture, exemplified by positive attitudes and motivations of firm staff, was identified as an organisational enabler for SCC (Rizos et al., 2016). Related to this is the enabler of integrating CE within a company's strategy and goals (Tura et al., 2019). Conversely, a lack of urgency or management support for CE as well as a lack of integration of CE in the company strategy, mission, vision, goals are mentioned as SCC barriers at firm-level (Govindan and Hasanagic, 2018; Kirchherr et al., 2018; Tura et al., 2019). A premium brand image and differentiation strategy enables SCC because it provides opportunities for companies to integrate activities such as repair, refurbishment or remanufacturing into their offerings (Hofmann, 2019; Tura et al., 2019). Another barrier is the added complexity for planning and implementing SCC, particularly in regard to the predictability and reliability of reverse flows (Linder and Williander, 2017; Rizos et al., 2016; Vermunt et al., 2019) as well as

the complexity of developing lease contracts, in which product ownership is retained (Vermunt et al., 2019).

A financial enabler is the attractiveness of SCC practices and the related technologies, which manifests itself in a low investment risk (Rizos et al., 2016). Financial risks can stem from high up-front investments needed as well as from product cannibalisation from selling remanufactured or used products (Linder and Williander, 2017). Other financial barriers are the increased financial risk of product ownership, due to technical, functional, aesthetic, or economic obsolescence risks of products (Linder and Williander, 2017; Zeeuw van der Laan and Aurisicchio, 2020).

Digital technologies such as remote monitoring enable manufacturers to increase the contribution of PSSs to SCC (Alcayaga, Wiener and Hansen, 2019; Zeeuw van der Laan and Aurisicchio, 2020). These technologies allow the monitoring of product condition and usage, thereby facilitating maintenance, repair, remanufacturing, and recycling (Alcayaga, Wiener and Hansen, 2019). Another enabler are skills and capabilities in designing products for SCC, for example product modularity or durability (Zeeuw van der Laan and Aurisicchio, 2020). Regarding barriers, a firm may not have the internal know-how to successfully implement the technologies and processes needed for circularity in PSSs, such as monitoring devices (Rizos et al., 2016) or remanufacturing activities (Linder and Williander, 2017).

External contextual factors

Externally, fast industry innovation cycles can inhibit the contribution of PSSs to SCC, by increasing the rate at which products become technically, functionally, aesthetically or economically obsolete (Linder and Williander, 2017; Zeeuw van der Laan and Aurisicchio, 2020). For example, implementing remanufacturing is easier in contexts in which the attractiveness of a product is less determined by fashion trends or its aesthetic attributes (Linder and Williander, 2017; Zeeuw van der Laan and Aurisicchio, 2020). Another barrier is a lack of customer acceptance, which can manifest itself in an unwillingness to adopt PSSs

(Vermunt et al., 2019) or to acquire refurbished products due to quality concerns (Kühl et al., 2019).

In the supply chain category, an enabler is the availability of suitable partners (Rizos et al., 2016). In addition, having open and collaborative relationships with supply chain partners can help provide new opportunities for SCC, such as cross-sector waste and by-product exchanges (Kühl et al., 2019). In addition, effectively implementing reverse flows, such as recycling, may be hindered by a country's lack of infrastructure, such as sorting and collecting (Corvellec and Stål, 2017).

Supportive funds, taxation or subsidy policies can have an enhancing effect on a firm's efforts to transition to SCC (Kühl et al., 2019; Tura et al., 2019). Potential barriers are a lack of incentives that promote slowing and closing of resource loops, such as high value added taxes (VAT) on services, such as maintenance and repair (Kirchherr et al., 2018; Vermunt et al., 2019). Waste and recycling regulations may inhibit circularity, by failing to provide coherent definitions and classifications of wastes and by-products, thereby inhibiting recycling (Govindan and Hasanagic, 2018; Rizos et al., 2016; Tura et al., 2019). Finally, lacking quality standards, for example, for refurbished products can inhibit consumer acceptance in the market (Vermunt et al., 2019).

Table 4-1 List of expected internal and external contextual factors of PSSs' relationship with SCC

Category	Enablers	Source	Barriers	Source
Internal				
Organisational	Pro-environmental culture	Rizos et al. (2016); Sousa-Zomer et al. (2018b)	Lack of management support for CE	Govindan and Hasanagic (2018); Kirchherr et al. (2018); Tura et al. (2019)
	Integration of CE in company strategy and goals	Tura et al. (2019)	More complex management and planning process	Linder and Williander (2017); Rizos et al. (2016); Vermunt et al. (2019)
	Premium brand image/ Differentiation strategy	Tura et al. (2019); Zeeuw van der Laan and Aurisicchio (2020)		
Financial	Financial attractiveness of practices or technologies	Kühl et al. (2019); Rizos et al. (2016)	Risk of product sales cannibalisation	Linder and Williander (2017)
			Lack of a clear financial business case	Vermunt et al. (2019)
			Risk of capital tied up in products	Linder and Williander (2017); Rizos et al. (2016)
			Lack of financial resources	Kirchherr et al. (2018); Rizos et al. (2016)
Technology & Knowledge	Digital capabilities (collection of product information & data)	Alcayaga, Wiener and Hansen (2019); Zeeuw van der Laan and Aurisicchio (2020)	Lack of technical know-how	Rizos et al. (2016)
	The ability to design products for circularity	Zeeuw van der Laan and Aurisicchio (2020)		
External				
Market			Speed of industry innovation cycles	Linder and Williander (2017); Zeeuw van der Laan and Aurisicchio (2020)
			Lack of customer acceptance for circular products or business models	Kirchherr et al. (2018); Kühl et al. (2019); Vermunt et al. (2019); Zeeuw van der Laan and Aurisicchio (2020)
Supply Chain	Suitable partners available	Rizos et al. (2016)	Lack of infrastructure to handle returns/wastes (e.g., recycling networks)	Corvellec and Stål (2017)
	Cross-sector collaboration	Kühl et al. (2019); Tura et al. (2019)	Lack of supply network support (e.g., suitable partners)	Rizos et al. (2016)

Category	Enablers	Source	Barriers	Source
Regulatory	Supportive funds, taxation, subsidy policies	Kühl et al. (2019); Tura et al. (2019)	Ineffective waste/recycling regulations	Govindan and Hasanagic (2018); Rizos et al. (2016)
			Policies that promote material consumption over services	Kirchherr et al. (2018); Vermunt et al. (2019)
			Lacking quality standards (e.g. for refurbished products)	Vermunt et al. (2019)

4.3 Methodology

4.3.1 Research strategy

This paper follows a theory testing research strategy (Ketokivi and Choi, 2014). Case study methodology is well suited to the “how” question and the explanatory nature underlying this research (Yin, 2018). The contribution of PSSs to SCC is used to test the contextualised logic of the NRBV. The research was guided by *a priori* theoretical considerations and hypotheses that were deduced from the literature. The case study meets the duality criterion (Ketokivi and Choi, 2014), by being on one hand situationally grounded in the context of PSSs and on the other hand being embedded in the NRBV. Nevertheless, while a theory testing approach is driven by theoretical deduction, it is not exclusively limited to it (Ketokivi and Choi, 2014). The analysis of contextual factors that enable and inhibit the contribution of PSSs to SCC, whilst guided by *a priori* considerations, remained open to unanticipated findings. The research design is based on a multiple case study of three manufacturers that offer PSSs in the UK and Germany, enabling the phenomenon to be studied within its real-life context. Case selection was based on literal replication logic (Yin, 2018). According to this logic, the hypotheses are expected to be true across all cases and the cases are expected to corroborate each other (Yin, 2018).

4.3.2 Case study context: PSSs in manufacturing

The focus on equipment manufacturing firms in the UK and Germany is representative of existing sectors and countries in the PSS literature (Baines and Lightfoot, 2013; Baines and Shi, 2015). As outlined in Table 4-2, the study involves three manufacturers that offer PSSs, who operate in business-to-business (B2B) markets. To increase the external validity of the findings, context diversity was sought in terms of the industry as well as the speed of product innovation cycles in an industry. The speed of product innovation cycles was chosen since it was previously identified as a barrier to SCC (Linder and Williander, 2017).

The units of analysis are the different PSSs within the same company to minimise the potential impact of extraneous variation (Eisenhardt, 1989). Table 4-2 provides an overview of the different case companies. The units of analysis of the three companies were as follows:

***Computerco*:** Customers who buy notebook computers have the option for product recovery services at end-of-use. This product-oriented PSS includes the removal of outdated equipment from the customer, safely deleting sensitive data, as well as responsibly repurposing or recycling the equipment. Alternatively, customers can lease equipment (use-oriented PSS). The company does not offer a result-oriented PSS.

***Toolco*:** Tools can be acquired through a traditional sales model with an extended warranty (product-oriented PSS) as well as through a leasing contract (use-oriented PSS). In the product-oriented PSS, the customer buys the product and receives a two-year warranty period for all product repairs. After that period, any repair costs are capped at 30-40% of the original tool price. In the use-oriented PSS, the manufacturer retains product ownership and leases the tools to the customer for a period between 24 to 48 months, depending on the tool type. The company does not offer result-oriented PSS.

***Windco*:** Windco offers a basic annual service (product-oriented PSS) as well as an availability contract (result-oriented PSS). The product-oriented PSS is targeted at customers with smaller wind-farms or those that already have internal servicing capabilities. The result-oriented PSS is designed to provide risk-free turbine availability over the entire contract term. The company does not offer use-oriented PSS.

Within each of the three case companies only two of the three possible PSSs were present. This can be explained by the fact that the PSS's value propositions do not always fit customer needs across different contexts (Smith, Maull and Ng, 2014).

Table 4-2 Overview of case companies

	Computerco	Toolco	Windco
Case Companies			
Organisation	North American manufacturer of office equipment	European manufacturer of power tools	European manufacturer of wind turbines
Product description	Computer notebooks	Power tools for construction industry	Wind turbines
Speed of industry innovation cycles	~3-5 years	~5-7 years	~7 years
No. of employees	50,000+	25,000+	8,000+
Annual Turnover	~£45 Billion	~£5 Billion	~£8 Billion
Geography	United Kingdom	United Kingdom	Germany
Units of Analysis			
Product-oriented PSS	Product Recovery Services	Extended Warranty	Annual Service
Use-oriented PSS	Leasing Contract	Leasing Contract	N/A
Result-oriented PSS	N/A	N/A	Availability Contract
Data Collection			
Interviews	2	8	9
Interviewees	Manager Sustainability Services & Stewardship; Senior Director for Global Sustainable Impact Operations (Global CE lead)	Marketing Director, Marketing Manager, Sustainability Director, Account Manager (x3), Product Manager, Head of Repair Services	Business Development Manager; Operations Manager (x2); Product Lifecycle Management Director; Research & Development Manager; Service Director (x2); Sustainability Manager (x2)
Documents (e.g. reports, presentations, press briefings)	23	17	33
Quantitative data	Lifecycle assessment data	Data on product returns	-
Observations	-	1 (2-hour visit to service & repair centre)	-

4.3.3 Data collection

Construct validity was ensured through both triangulation of methods and data sources (Yin, 2018). Method triangulation was achieved by collecting data through semi-structured interviews as well as documentary, archival or database evidence, and observations to help verify information from interviews (Yin, 2018). Data source triangulation was achieved by using multiple informants or documents to corroborate findings. The data collection involved both quantitative and qualitative evidence (Eisenhardt, 1989). This helped to provide explanations for quantitative findings and to ultimately develop a more holistic understanding of the case (Eisenhardt, 1989).

Interview data was collected with 19 key informants from the case companies with a detailed understanding of the phenomenon under investigation, between July 2019 and April 2020. Each interview lasted between thirty minutes and one-and-a-half hours and was transcribed verbatim for coding and analysis. As depicted in Table 4-2, only two interviews were conducted with Computerco. This is due to the fact that the interviewees were highly knowledgeable of the studied phenomenon with one interviewee being responsible for increasing the sustainability of its business services and the other interviewee being Computerco's global lead for CE implementation. In addition, since Computerco is a frontrunner in CE implementation, there was a large amount of secondary information available, such as company reports and even a lifecycle assessment, which included quantitative data on the product lifetimes, repair and refurbish rates, and environmental impacts of the product- and use-oriented PSSs. Documentary evidence included internal presentations, reports, contracts or press briefings that described the scope of PSSs, the implementation of SCC practices as well as slowing and closing outcomes.

In the case of Toolco, one two-hour visit was made to the service and repair centre, in which repair and decommissioning processes were observed. Apart from this qualitative evidence, the data collection also included quantitative evidence, such as database evidence on product returns or component value.

4.3.4 Data analysis

Template analysis was used for the within-case data on PSSs characteristics, SCC practices, SCC outcomes, and contextual factors (King, 2012). Template analysis is a style of thematic analysis that allows for flexibility of coding by using an *a priori* coding structure, which guides the researcher in finding relevant information (King, 2012). Nevertheless, template analysis allows for codes to evolve as new findings emerge, such as inserting, deleting, or merging codes (King, 2012). In addition, a full pattern matching technique was employed to examine causal relationships and to build explanations (Yin, 2018). This technique was used for both the within-case and the cross-case analysis. The cross-case analysis used the tactic of finding differences and similarities between the cases (Eisenhardt, 1989). The analysis was conducted using NVivo. Examples of the case study evidence is provided in Appendix C.5.

4.4 Results

4.4.1 The application of PSSs

This section outlines the application of PSSs across the three case companies. The results are presented in Table 4-3. In regard to product ownership, the customer was the product owner in all three product-oriented PSS. In the use-oriented PSSs, Computerco and Toolco both retain product ownership. Contrary to expectation, the customer retained product ownership in Windco's result-oriented PSS. Since wind turbines are large industrial assets with long lifetimes of 20-25 years, retaining ownership of serviced wind turbines would tie up too much of Windco's capital. Windco focuses on providing operation and maintenance services, while financing is typically provided by banks or through investor equity.

Across all units of analysis, the customer was the user of product. In regard to product decision-making, the only unit of analysis in which the manufacturer had decision-making power was in Windco's result-oriented PSS. In this offering, Windco decides when and how to carry out operation and maintenance activities to provide optimised availability outcomes to the customer.

In the case of Computerco's product-oriented PSS, customers only have a few customisation options in regard to location and service for equipment pick-up. The use-oriented PSSs on the other hand are much more customised. Customers can choose between three plans: standard, enhanced and premium, which have varying configurations and support levels regarding IT security, software upgrades or remote assistance.

In Toolco, both the product- and use-oriented PSS had low degrees of customisation. The product-oriented PSS is a standard warranty package that comes when buying the products. It includes a non-customisable two-year free repair period and cost cap beyond that. While the use-oriented PSS has a larger scope of activities than the product-oriented PSS, customisation remains low. The only customisation option for Toolco customers is in regard to the contract duration.

In Windco, the difference in customisation between the units of analysis was the greatest. The product-oriented PSS is a standard checklist of items, such as changing the filters and oils, and a basic turbine inspection that cannot be altered. The result-oriented PSS on the other hand is a complex and highly customised offering that may also include coordination of electrical infrastructure or optional trainings.

Apart from the Toolco case, the relationship intensity was also higher in result-oriented and use-oriented PSSs compared to product-oriented PSSs. In the case of Toolco, the relationship intensity was high in both the product-oriented and use-oriented PSSs, with account managers visiting customers regularly to identify potential customer needs or provide training and support regardless of the PSS type.

> *"Our account managers try to visit customers once a week or at least once a month, depending on the size of the customer. (…) The customer buying our tools outright may only have a small portion of these tools and so you really have to keep the customer engaged and buying so they almost require more intense observation and*

management than a fleet [use-oriented PSS] customer." - Toolco, Product Manager (Int3)

In Computerco's product-oriented PSS, the relationship intensity is low, since the equipment pick-up is a singular transaction without any further engagement between Customer and Computerco. In the use-oriented PSS, however, Computerco has an ongoing relationship and exchange with customers during the contract period. The intensity of the relationship depends on the customer needs.

"Some customers want people on-site to manage their PC fleet, some [customers want] a person who can respond to questions, but other customers may want an onsite or an off-site helpdesk." - Computerco, Sustainability & Services Manager (Int7)

In the Windco case, the relationship intensity is low since the interaction is limited to an annual or bi-annual check-up with the customer. In comparison, the relationship intensity is much higher in the result-oriented PSS. Each site has a dedicated operations manager who provides regular updates to the customer on availability figures, or planned service works.

"Our contact with customers is at least weekly and we have contractual monthly reports that we share. We often share daily reports with them as well and the customer often provides us with feedback if they are not happy with the daily production." - Windco, Operations Manager (Int14)

Manufacturers bear more product-related risks in the result-oriented and use-oriented PSSs compared to the product-oriented PSSs. While Computerco takes on no risks in the product-oriented PSS, they take on various damage and IT security risks in the use-oriented PSS, depending on the scope of the offering. Toolco takes on risks associated with the products in both the product- oriented and use-oriented PSSs. In the product-oriented PSS, Toolco internalises risks of product breakdowns, while in the use-oriented PSS, they also internalise behavioural risks, such as accidental damages, theft, losses as well as tool

exchange to prevent customer downtime. The difference in regard to risk transfer between the units of analysis is the most pronounced in Windco:

> *"The basic contract has very limited risks for us; For the performance-based contracts, the risk is large because we take the complete risk of downtime of turbines. If five blades break within one year, then the risk on the availability is on us."* - Windco, Service Manager (Int11)

The payment mechanisms in the product-oriented and use-oriented PSSs were based on either a single mark-up price or a fixed fee. Performance-based payment mechanisms were only present in Windco's result-oriented PSS, in which results were based on a time-based availability (95%) performance-based contract that includes pain and gain sharing mechanisms in case the agreed upon results are not reached or exceeded.

Table 4-3 PSS characteristics across the units of analysis

PSS Characteristics	Computerco		Toolco		Windco	
	Product-oriented PSS	*Use-oriented PSS*	*Product-oriented PSS*	*Use-oriented PSS*	*Product-oriented PSS*	*Result-oriented PSS*
Product Owner *(Manufacturer or Customer)*	*Customer*	*Manufacturer*	*Customer*	*Manufacturer*	*Customer*	*Customer* –Windco does not retain turbine ownership (turbine project finance).
Product User *(Manufacturer or Customer)*	*Customer*	*Customer*	*Customer*	*Customer*	*Customer*	*Customer*
Product Decision-Maker *(Manufacturer or Customer)*	*Customer*	*Customer*	*Customer*	*Customer*	*Customer*	*Manufacturer* -Windco plans and carries out service operations.
Customisation *(High or Low)*	*Low* – Pretty standard. Equipment pick-up can be specified.	*High* – Three different service levels with additional scope options.	*Low* - Standardised offering that comes with all purchased tools.	*Low* – Standardised offering. Contract length only customisation option.	*Low* – Standard inspection checklist.	*High* – Completely customised to meet customer requirements.
Relationship Intensity *(High or Low)*	*Low* – Single transaction without recurring relationship.	*High*– Ongoing service relationship; Option for co-located staff.	*High* – Regular visits to customer sites, regardless of business model.	*High* - Regular visits to customer sites, regardless of business model.	*Low* – Service (1-2 times/year) , otherwise no interaction.	*High* – Co-located staff, regular exchange (e.g. phone calls with customer)
Risk *(Customer or Manufacturer)*	*Customer* - No risk transfer	*Manufacturer* - Computerco assumes repair, damage, IT & security risks.	*Customer* - repairs for free for two years, repair costs are capped after year two.	*Manufacturer* - free repairs, theft & damage protection to loan tools.	*Customer* - Customer bears operational risks.	*Manufacturer* - Windco takes on turbine availability risks.
Payment Model *(Mark-up, Fixed-fee, , Performance-based)*	*Mark-up* – Payment depends on residual equipment value and service scope.	*Fixed fee* - Fixed monthly leasing fee depends on scope of offering.	*Mark-up* – Fixed price for tools.	*Fixed fee* - Fixed monthly leasing fee depends on scope of offering.	*Fixed fee* – Fixed fee depending on scope of service.	*Performance-based*– Payments based on turbine availability

4.4.2 Slowing and closing across the PSSs

This section outlines the results for the slowing and closing across the three cases. The highlights are presented in Table 4-4.

4.4.2.1 Initial lifetime

At Computerco, the same notebook computers are used in both the product-oriented and the use-oriented PSSs. The notebook in this study has an expected initial lifetime of two to four years. In the product-oriented PSS, the lifetime depends on how long the customer decides to use it. Spare parts are available for up to five years after production. In the use-oriented PSS, the lifetime depends on the leasing contract. Especially institutional customers, such as hospitals, often require computer systems to last longer, resulting in contracts of up to five years.

The expected lifetime for the studied Toolco product ranges from two to four years, depending on the use intensity. In some cases, sold tools reach a lifetime of 15 or even 20 years. Toolco supports lifetime extension in the product-oriented PSS, by offering free repairs in the first two years and capping repair costs beyond that at 30-40% of the product price. In the use-oriented PSS, the contracts last between two to four years, depending on the tool type. About a third of the customers extend the lease period by about 3-5 months, if they want to wait for the release of a new tool version or a project is close to finishing.

Windco turbines are designed to last around 20-25 years. In the product-oriented PSS, the customer is responsible for operation and maintenance activities, while Windco only carries out the standard annual service. Stand-alone add-on services are available, such as refurbished spare parts or upgrades. In the result-oriented PSS, Windco takes over the responsibility for service and maintenance activities. The main performance indicator for Windco is the customer's levelised cost of energy – it is capital and operational expenditures, so overall cost, divided by the annual energy production for 20-30 years. High performance depends on low levelised cost. There are two levers: either reducing the cost of turbines, or

increasing the annual energy production, for example, by extending the lifetime or repowering to a larger turbine.

Due to their service expertise and know-how, Windco is able to offer customers lifetime extension services that extend turbine lifetime by up to 10 years on top of the planned lifetime of 20-25 years. It achieves this while stabilising the operation and maintenance costs of the turbine at the level of a 10-year-old wind farm. To do this, they optimally deploy condition monitoring, preventive and corrective upgrades over the product lifecycle. Compared to the product-oriented PSS, Windco has the advantage that it can guarantee low operational costs in the result-oriented, thereby offering a low-risk business case for turbine lifetime extension. Nevertheless, turbine lifetime extension, does not only depend on Windco, but also on customer preferences:

> *"The best way to extend the lifetime is to limit the loads on the turbine. This decision, ultimately depends on the preferred cash flow of the customer. It is a balance of both short term revenue as well as extending lifetimes. Customers want to minimise the levelised cost of energy. If you can have a very long lifetime, your cost per KW hour is rather low."* - Windco, Service Manager (Int11)

In the case that turbine lifetime extension is not economically feasible, customers have the option to decommission the turbine and sell it for reuse in a different location. This can be viable if there is no substantial business case for product life extension at one site (e.g., expiration of subsidies), but the turbine is still in good technical condition.

4.4.2.2 Refurbishment contribution

In Computerco's product-oriented PSS, the return rate of products is unclear, since the use of the recovery service is on a voluntary basis. In the use-oriented PSS, Computerco recovers more than 75% of the notebooks. In both cases, the returned notebook computers are returned to Computerco or its network of certified partners, where around 80% are refurbished and 20% recycled. The refurbished notebooks are resold for a second lifetime between one and three

years. Beyond this second lifecycle, the company does not recover the notebook computers, which hinders the possibility for an additional refurbishment contribution. As a result, the company wants to start offering lease agreements (use-oriented PSS) for refurbished notebooks as well within the next year:

> *"We do not want the returned products to go on the open market but want to bring them back into our own economic cycle. Within the next year, you will see products moving through multiple cascades: from large commercial and public sector customers through to consumers."*
> - Computerco, Circular Economy Director (Int9)

In the case of Toolco, there is no significant refurbishment contribution. In the product-oriented PSS, Toolco does not recover and refurbish any tools. In the use-oriented PSS, customers return around 85% of the leased tools. Around 60% of these are still usable, suggesting potential for reuse. Of the tools that are returned, 1-3% are in good enough condition to be reused as loan tools. The rest of the returned tools are decommissioned and subsequently recycled. Before decommissioning, Toolco recovers the rotor and electronics (about 10% of the tool value), which are refurbished and reused in repair services.

Due to the size and immobility of wind turbines, refurbishment does not occur on a product-level, but rather on a component-level. Windco offers component refurbishment services for large components, such as generators, gearboxes, main bearings, shafts, and blades as well as smaller electronic components. Compared to new components, refurbished components have the same performance specifications and expected lifetime but cost around 20% less. Component refurbishment is offered in addition to the product-oriented or result-oriented PSSs. It depends on the component damage and whether refurbishment is economically viable for the customer. Due to its potential for cost reduction, the refurbishment program is an important pillar in ensuring the feasibility of turbine lifetime extension. The refurbishment programme positively contributes to the slowing and closing of resource loops.

> *"We have a pool of working refurbished components, which we deliver to the site and install in the turbine. We then take these old and broken*

components, refurbish them "as-new" and keep them in our pool for future installation." - Windco, Business Development Manager (Int17)

From a technical perspective, multiple refurbishment cycles are possible for components. The number of cycles is limited by the amount of compatible turbine models in the market.

4.4.2.3 Recycling contribution

The Computerco notebook examined in this study did not contain any recycled plastic content and has a recyclability of 95%. In Computerco's use-oriented PSS, more than 75% of the equipment is returned and about 20% recycled. As previously explained, Computerco does not recover equipment after the second lifecycle. For the product-oriented PSS, it is not clear what percentage is recycled. In the UK, the recovery rate for IT equipment is currently at close to 50% (mass basis – tonnes of equipment put on the market and subsequently recovered) (EUROSTAT, 2020). Nevertheless, this is likely to be mainly accounted for by business customers rather than consumers, due to data, compliance, and environmental risks associated with not recycling computer equipment properly.

The Toolco tool has a recyclability of around 95%. They also use about 10% recycled material, mainly metals, in their products. In the product-oriented PSS, the customer is responsible for recycling tools at end-of-life. For electrical and electronic tools in the UK, the recovery rate as of 2017 is about 21% (mass basis–tonnes of equipment put on the market and subsequently recovered) (EUROSTAT, 2020). The relatively low level of recovery can be explained by a large hibernating stock or tools being sold off to secondary markets:

"When I go out to visit customers, they have pallets of old tools lying around. They say that someday they will send it back to us or recycle them." - Toolco, Account Manager (Int18)

In the use-oriented PSS, Toolco recovers around 85% of tools, of which around 97-99% are given to recycling:

> *“We do not want to get the Fleet tools [use-oriented PSS] out into the market because quite frankly they can end up in foreign countries – we try and control that as much as possible to protect our brand.”* - Toolco, Head of Repair Services (Int8)

For Windco, recycling is not yet a pertinent issue, because the vast majority of wind turbines are still in use. About 80-90% of the mass of a wind turbine can be recycled (Bundesverband Windenergie, 2019). The customer is responsible for the decommissioning of the turbines. One of the drawbacks of this strategy is that Windco is not able to recover used components for refurbishment or recycling at end-of-life. In Germany, wind turbines are required by law to be recycled.

Table 4-4 Comparison of slowing and closing across the cases

	Computerco		**Toolco**		**Windco**	
	Product-oriented PSS	*Use-oriented PSS*	*Product-oriented PSS*	*Use-oriented PSS*	*Product-oriented PSS*	*Result-oriented PSS*
Initial Lifetime	2-4 years. Spare parts available for 5 years after end of production.	Same products as in product-oriented PSS. Contracts typically range from 3-5 years. Maintenance and repair included in the lease agreement.	2-4 years. Free repairs for the first two years, then capped at 30-40% of new tool price. Depending on use intensity, the lifetime can reach up to 15-20 years.	2-4 years. About 30% of customers extend contract by 3-5 months.	20-25 years standard lifetime. Different stand-alone service modules available to help extend product life. Lifetime extension depends on cost of energy, customer's business case. Potential for turbine reuse abroad.	20-25 years. Extension by up to 10 years possible. Windco can minimise costs compared to product-oriented PSS, but lifetime extension depends customer preferences. Potential for turbine reuse abroad.
Refurbishment Contribution	Return rate unclear, since on a voluntary basis. ~80% of all returned products are refurbished. Refurbished lifetime expected to be between 1-3 years. Products currently lost to open market after they are refurbished and resold.	Around 75% of use-oriented PSS products are returned. ~80% of all returned products are refurbished. Refurbished lifetime expected to be between 1-3 years. Products currently lost to open market after they are refurbished and resold.	No refurbishment and reuse of used tools.	About 85% of tools are returned. About ~1-3% in good enough condition to be reused as loan tools.	No difference between the units of analysis. Component refurbishment available for several large and small components. Available to both PSS types. Same expected lifetime and performance as new components, for 80% of the cost.	
Recycling Contribution	In product-oriented PSS, return rate not clear. Currently around 50% for computers in the UK.	About 75% of use-oriented notebooks returned and ~20% of those are recycled (~95% recyclability).	Recycling rate of power tools in the UK around 21%. Customers typically have large unused stock of old tools.	Around ~85% of tools recovered after end of contract. Of these around ~91% are recycled.	No difference between the units of analysis. Not yet relevant, since vast majority of turbines are still in use. Customers required to recycle turbines at end-of-life. Expected to be high, since customers required by law to decommission and recycle.	

4.4.2.4 Slowing and closing outcomes

Figure 4-2 is a graphical abstraction of the slowing and closing outcomes across the six units of analysis. The horizontal axis represents the degree of slowing, whereas the vertical axis describes the degree of closing. The PSS types are arranged along the two axes, with result-oriented PSSs having the potential for the highest degrees of slowing and closing. This classification is based on the conceptual map in Figure 4-1. Computerco's planned update to the use-oriented PSS, in which they would lease equipment across multiple lifecycles is included as a potential improvement to both slowing and closing. The outcomes for the units of analysis in relation to the hypotheses in Section 4.2.3 are presented below. They results are summarised in Table 4-5.

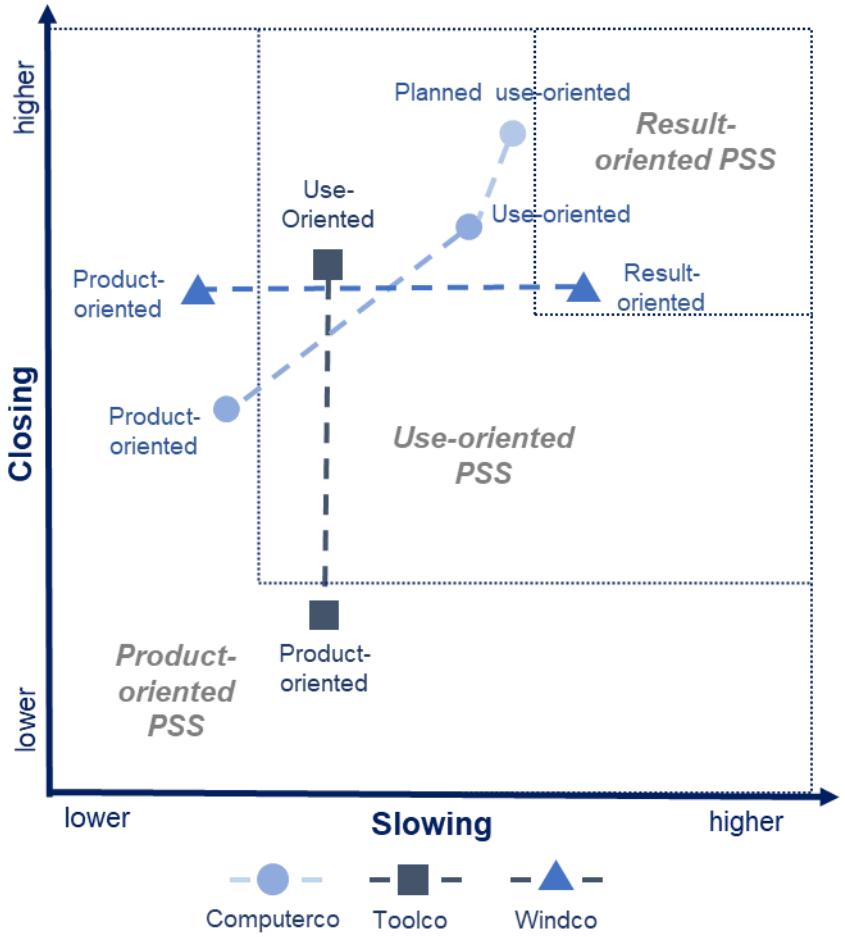

Figure 4-2 Slowing and closing outcomes across the three case studies

Hypothesis 1a and 1b compare the slowing and closing outcomes of use-oriented and product-oriented PSSs. In terms of slowing (H1a), the findings from the Computerco and Toolco cases are mixed. In both cases, the initial product lifetime is similar in both the product-oriented and the use-oriented PSSs. Both companies employ the same products with comparable expected lifetimes across both business models. The main difference in slowing between the two PSSs stems from the refurbishment contribution. Computerco refurbishes and resells returned equipment, thereby creating an additional product lifecycle and, hence, slowing resource loops. Compared to the product-oriented PSS, it is easier for Computerco to slow resource loops in the use-oriented PSS, since they retain product ownership, which ensures a high degree of product returns (more than 75%). Toolco retains product ownership in the use-oriented PSS. However, there is no refurbishment contribution, since the returned tools are decommissioned and recycled. As a result, Toolco's use-oriented PSS does not contribute to a slowing of resource loops in comparison to the product-oriented PSS. Hypothesis (H1a) is therefore not supported.

The findings confirm H1b, namely that use-oriented PSSs have a higher degree of resource loop closure than product-oriented PSSs. This hypothesis is supported in both cases. As predicted in the hypotheses, the retention of product ownership in the use-oriented PSS ensures that products are returned from the customer after use (~75%). In the case of Computerco, the company is also recovering used computers from its customers through their product-oriented PSS. This is driven by business customers' concerns around data privacy, security, as well as increasing environmental concerns. Computerco refurbishes and resells the collected computers (~80%), while a smaller percentage are recycled (~20%). The main shortcoming in terms of closing is that the company currently does not recover the products after the second lifecycle. The company's proposed change to extend the use-oriented PSS to different customer segments for multiple lifecycles would help to overcome this.

The benefit of use-oriented PSS over product-oriented PSS is most apparent in Toolco. Compared to the product-oriented PSS, in which many customers do not

return used tools, Toolco is able to recover about 85% of tools and recycle around 91% of those. Hypothesis (H1b) is therefore supported.

According to Hypothesis 2a and 2b, the slowing and closing of resource loops in result-oriented PSSs is higher than in product-oriented PSSs. In regard to slowing (H2a), Table 4-4 shows that the slowing contribution stems from an extended initial turbine lifetime. In the result-oriented PSS, Windco manages the service and maintenance of the wind turbine. In the product-oriented PSS, however, Windco only conducts the minimum annual service. By optimising maintenance activities in the result-oriented PSS, Windco is able to extend the initial lifetime of 20-25 years by up to 10 more years.

Finally, the performance-based payment mechanisms in the contract ensure that Windco is incentivised to maximise turbine availability at minimal cost. While product-oriented PSS customers can also conduct operation and maintenance services to extend product lifetimes, Windco can leverage the experience gained from maintaining more than 70% of its turbines, which allows them to transfer design improvements to the existing fleet, thereby making turbines more reliable and less costly to operate. The main benefit of the result-oriented PSS compared to the product-oriented PSS is that Windco is able to optimise maintenance and reduce operating costs to provide the customer with a viable business case for lifetime extension of up to 10 years.

In regard to closing (H2b), current benefits stem from the closed-loop of component refurbishment at Windco. This is offered, however, across both PSSs, which is why there is no benefit of result- over product-oriented PSSs. Regarding end-of-life recycling, the vast majority of Windco's installed wind turbines are still in use. Nevertheless, since the customer is responsible for recycling at end-of-life, both PSSs contribute equally to the closing of resource loops. The recycling of wind turbines is still expected to be high, since turbine owners are by law required to build up capital reserves over the lifetime to ensure proper decommissioning and recycling. Since there is no benefit of result-oriented PSSs compared to product-oriented PSSs, hypothesis (H2b) is not supported.

Table 4-5 Results of hypotheses across the cases

Hypotheses	**Computerco**	**Toolco**	**Windco**
H1a (use-oriented PSSs increase slowing)	*Supported* – Majority of notebooks from use-oriented PSS refurbished and resold.	*Not supported* – Lack of refurbishment & reuse shows Toolco's focus on closing, not slowing.	
H1b (use-oriented PSSs increase closing)	*Supported* – High recovery rate of use-oriented PSS, but currently lost after the second lifecycle.	*Supported* – many tools from product-oriented PSS likely unused stock. Vast majority of use-oriented PSS tools are recovered and recycled.	
H2a (result-oriented PSSs increase slowing)			*Supported* – Windco has strong expertise in, and advantage in providing strong business case for lifetime extension.
H2b (result-oriented PSSs increase closing)			*Not supported* – vast majority of turbines still in operation. Recycling contribution expected to be the same, since customer is responsible for recycling regardless of PSS type. No benefit of either result- or product-oriented PSS.

4.4.3 The role of contextual factors

In the following section, the findings on the role of internal and external contextual factors are presented. A summary of the results is shown in Tables 4-6 and 4-7.

4.4.3.1 Internal contextual factors

Organisational enablers of a pro-environmental culture and an integration of CE into company strategy were especially identified at Computerco.

> *"Our commitment to CE is a natural evolution from our 25-year-old recycling programmes. From the beginning, our founders had the principle of 'Global Citizenship' - behaving well towards the society that we are in is one of our core values."* - Computerco, Circular Economy Director (Int9)

The pro-environmental culture manifested itself in direct support from the CEO, for example, in employees joining climate protests or in developing local sustainability teams. Computerco also has a clearly formulated CE strategy that focuses on decoupling growth from consumption, transforming industry business models, and collaborating with partners and customers to increase SCC. This CE strategy is integrated into the strategy of every business unit:

> *"In the strategy of each business unit, there is one pillar called circular economy. So increasing circular economy is part of their key goals."* - Computerco, Sustainability & Services Manager (Int7)

Together, the pro-environmental culture as well as the integration of CE into the company strategy enable the slowing and closing of resource loops, because it encourages employees to find ways to increase the contribution of its PSSs to SCC:

> *"Being a responsible company is part of our DNA – and people are measured on that - and if you hear that all the time, you adhere to it. … There is a lot of thought around doing things better, such as cutting down onsite repairs, doing preventive maintenance before the unit is broken to help consolidate the customer visits."* - Computerco, Sustainability & Services Manager (Int7)

In the case of Toolco on the other hand, this enabler was not present, as the company was still developing its environmental strategy.

> *"Last year we had the first top down environmental strategy. But that has been recognised by the company and we now have a clear direction to further develop the sustainability strategy."* - Toolco, Sustainability Director (Int6)

For Toolco and Windco, premium brand positioning was an organisational enabler. Windco focus on producing high quality and durable turbines:

> *"We were always a quality leader. Of course, we also had a few warranty cases, but compared to other companies, especially with*

regard to the blades, we perform well." – Windco, Product Lifecycle Management Director (Int10)

This enables a slowing of resource loops, because it helps ensure the durability of wind turbines. Toolco, markets itself as a premium brand, which stands against the "throw-away-buy-again" culture in construction:

"Our value proposition as a premium brand is to meet our customers' strategic concerns, such as productivity, health and safety, tool durability." – Toolco, Marketing Director (Int4)

Toolco's premium brand image enabled SCC through the design of long-lasting, durable and highly recyclable tools as well as through the provision of extensive repair services. Nevertheless, the premium brand image also inhibited a slowing of resource loops, particular through refurbishment.

"Up to now there has been a bit of reluctance within the company in regard to refurbishment just because we are a premium brand and there wasn't the appetite to create a secondary brand or cannibalise the market for ourselves…" -Toolco, Sustainability Director (Int6)

"By us openly offering a cheaper, inferior product, it could fundamentally undermine what we as a premium brand stand for." - Toolco, Marketing Director (Int4)

Financial barriers were another factor that prevented tool refurbishment, in particular due to concerns of product cannibalisation:

"You do not want to have these tools resurfacing, because we want to promote the value proposition of those new tools and encourage their sale." - Toolco, Head of Repair Services (Int8)

Conversely, Computerco was able to overcome this barrier by cascading used equipment over multiple lifecycles to different customer segments, from business to consumer markets:

> *"There is a cascade of customers; You might start off with a graphic designer and then the PC might go to a school or a hospital and then it might be used by a consumer who only needs it for emails and web browsing."*- Computerco, Circular Economy Director (Int9)

For Windco, a barrier to offering decommissioning services of turbines was the lack of a business case:

> *"Turbine decommissioning is nothing that you can build a scalable process around. It is suitable for more agile companies and more spontaneous solutions and approaches than large companies like Windco. Also, the margin is not large enough."* – Windco, Business Development Manager (Int17)

In regard to technology and knowledge factors, Windco utilises a range of remote diagnostic services in its result-oriented PSS, which help slow resource loops through preventive maintenance and upgrades. For example, its vibration diagnostics help catch faults, such as gear or main bearing damage, before they develop into serious damage, thereby helping extend the initial lifetime of products. These services keep a turbine's operating costs low, thereby creating a viable business case for lifetime extension. For example, preventive interventions and upgrades cost on average 80% less than corrective actions.

Toolco's use-oriented PSS comes with an internet-of-things enabled technology that informs customers of scheduled services as well as preventing that tools are lost. Even though it has information on product usage, it is still working on adjusting contract lengths to the actual amount used, to prevent an underutilisation of products:

> *"We are now also exploring to adapt our leasing contracts. For example, we are thinking of equipping our tools with an hour counter, which would make it possible to manage the return cycle in a way that tools would only come back to us at the end of their lifetime and not too much before."* - Toolco, Sustainability Director (Int6)

Across all three cases, products were designed for circularity. This included an emphasis on the durability, repairability, refurbish-ability as well as recyclability of their products.

Table 4-6 Enabling and inhibiting effect of internal contextual factors

Internal Contextual Factors	Computerco			Toolco			Windco		
	PO	UO	Effect/Explanation	PO	UO	Effect/Explanation	PO	RO	Effect/Explanation
ORGANISATIONAL									
Pro-environmental culture	x	x	**Enabler - Slowing & Closing:** Encourages employees to identify innovation opportunities to slow and close resource loops, for example by improving maintenance.						
Integration of CE in company strategy and goals	x	x	**Enabler - Slowing & Closing:** Encourages employees to identify innovation opportunities to slow and close resource loops, for example by improving maintenance.		x	**Barrier – Slowing**: Previously not integrated into company strategy. Development of strategy now underway.			
Premium brand positioning / Differentiation strategy				x	x	**Enabler - Slowing & Closing:** Brand image focused on the quality and dependability of products and services. Ensures durability, repairability, recyclability of products as well as quality repair services.	x	x	**Enabler - Slowing:** Focus on quality ensures product durability products and components.
					x	**Barrier – Slowing**: Refurbishment of products and perceived lower product quality regarded as undermining premium brand image.			
Lack of management support									
More complex management and planning process									

Internal Contextual Factors	Computerco			Toolco			Windco		
	PO	UO	Effect/Explanation	PO	UO	Effect/Explanation	PO	RO	Effect/Explanation
FINANCIAL									
Financial attractiveness of practices or technologies									
<u>New factor:</u> Serving different customer segments		x	**Enabler - Slowing**: Provides cascade opportunities to re-market refurbished equipment to different market segments, without risk of product cannibalisation.		x	**Barrier – Slowing:** Toolco only serves business customers. Increased risks of product sales cannibalisation, since no other segments are served.			
Risk of product sales cannibalisation					x	**Barrier - Slowing**: Company wants products returned from lease to ensure decommissioning, prevent cannibalisation of new product sales.			
Lack of a clear financial business case				x	x	**Barrier - Slowing & Closing**: No clear business case / customer need around SCC yet that Toolco can tap into (see regulatory factors).	x	x	**Barrier - Closing**: No clear business case for Windco to offer decommissioning and recycling services, due to low margins and volume.
Risk of capital tied up in products									
Lack of financial resources									
TECHNOLOGY & KNOWLEDGE									
Digital capabilities (collection of product information & data)					x	**Barrier - Slowing**: Usage data available, but not considered into contract lengths. Results in usable products being		x	**Enabler - Slowing**: Extensive use of remote monitoring and diagnostic technology helps prevent component damage, keep operation costs low,

Internal Contextual Factors	Computerco			Toolco			Windco		
	PO	UO	Effect/Explanation	PO	UO	Effect/Explanation	PO	RO	Effect/Explanation
						decommissioned before the end of their technical lifetime.			thereby extending product lifetime.
The ability to design products for circularity	x	x	**Enabler - Slowing & Closing**: Facilitates effective and efficient CE practices, such as repair, refurbishment, recycling.	x	x	**Enabler - Slowing & Closing:** Facilitates effective and efficient CE practices, such as repair, refurbishment, recycling.	x	x	**Enabler - Slowing & Closing:** Facilitates effective and efficient CE practices, such as repair, refurbishment, recycling.
Lack of technical know-how									

4.4.3.2 External contextual factors

This section identifies external contextual factors and their role in enabling or inhibiting the contribution of PSSs to a slowing and closing of resource loops. In both Computerco and Windco customer needs enabled SCC.

> *"I think a lot of companies are beginning to realise the importance of recycling properly to manage significant environmental, social responsibility as well as IT data security risks."* - Computerco, Circular Economy Director (Int9)

For Computerco, this helps to create a need in the market, which they meet through their recovery services (product-oriented PSS) as well as their use-oriented PSS.

In the Windco case, customer's price sensitivity enabled the introduction of refurbishment. The wind industry service market is currently experiencing a strong downward pressure on price. Since government-funded support schemes for customers are being phased out, customers are seeking new paths to reduce costs while also increasing returns. Windco is able to respond to this pressure, by offering refurbished components, which cost about 50% less compared to new parts. By reducing lead times for component repairs and reducing repair costs, the company is able to maximise the customer's return-on-investment.

Nevertheless, market factors also inhibited the relationship between PSSs and SCC. In the case of Computerco, a lack of customer acceptance for use-oriented PSSs inhibited the slowing and closing of resource loops:

> *"It requires quite a mindset change to go from procuring a product to procuring a product-as-a-service. Particularly in the public sector, many budgets are annualised and so planning that needs for a four- or five-year lifecycle is much more difficult to do."* - Computerco, Circular Economy Director (Int9)

In the case of Toolco, a careless attitude within the construction industry inhibited the impact of the product-oriented PSS on repairs and hence the slowing of resource loops:

> *"Even though customers have the incentive to send tools for repairs, they are fairly poor in doing so. In the construction industry, there is a culture or image of not really caring."* - Toolco, Account Manager (Int18)

There are also geographic differences in the customer attitudes towards SCC. Customers in Sweden, for example, are more aware of CE-related topics, such as product durability, than UK customers:

> *"Customers in Sweden are more aware of this durability and they're buying more into these value propositions of tool longevity compared to UK customers."* – Toolco, Marketing Director (Int4)

In terms of market barriers, the speed of industry innovation cycles was particularly encountered in Toolco and Windco cases.

At Toolco, recent technological innovations around cordless and smart tools resulted in shorter product lifecycles, thereby limiting the initial product lifetime and therefore the slowing of resource loops, particularly in the product-oriented PSS. A similar trend of shortening innovation cycles was observed in the wind industry:

> *"The lifecycles have become extremely squeezed due to high competition. Instead of 10-11 years (in total), we now only have 1-2 years to develop a new product and to run it for 3-4 years, before we phase it out again."* – Windco, Product Lifecycle Management Director (Int10)

In Windco, the combination of faster industry innovation cycles as well as a tougher competitive environment for older wind turbines exerted downward pressure on turbine lifetimes in both product- and result-oriented PSSs, because energy cost reduction is often more easily achieved by increasing the output, so

by repowering to a bigger turbine. Product lifetime extension is a trade-off of the expected revenues and the associated maintenance and operation costs. While Windco is able to minimise the maintenance and operation costs, problems remain for customers on the revenue side. One existing barrier is the low prices in energy markets. The majority of old systems have lower hub heights and larger area coverage and will therefore only be able to feed in electricity at higher wind speeds, when the market prices are lower due to increased supply (Quentin, Sudhaus and Endell, 2018). Specifically, in Germany, government subsidies for wind turbines are starting to be phased out. Paired with low energy prices and higher operating costs for older wind turbines, this will make it unfeasible for many wind turbine operators to invest in turbine lifetime extension, even though it is technically feasible (Quentin, Sudhaus and Endell, 2018).

Vertical integration was identified as a new supply chain enabler, particularly in Toolco and Windco. Toolco, for example, owns almost the entire value chain from product design to production, service, and recovery. This high degree of vertical integration helps to ensure service speed, quality, and reliability. In addition, since the company is vertically integrated, it is incentivised to optimise its service operation to increase its own profitability. This manifests itself in having repair and service staff involved in the product development process as well as in recovering components for refurbishment and reuse in the decommissioning process.

Windco is highly vertically integrated and maintains more than 70% of its own turbines. This enables the company to transfer latest design improvements to the existing fleet and future models. As a result, the company is able to make a range of hardware or software upgrades over the course of a turbine's lifetime, with the goal of making the turbine more reliable or easier to maintain. An additional barrier for the contribution of PSSs to SCC are competitive issues with customers:

> *"One option to make the current fleet management solution more circular is a model where you buy capacity – so having a number of tools of a specific type. This way, we could have more options to exchange tools– maybe even use refurbished ones. The main barrier*

for such a sharing model is that we could compete with some of our customers, who are tool-hire companies." – Toolco, Product Manager (Int18)

Another identified supply chain barrier is the supply of high quality recycled plastics in the market. One challenge for increasing the recycled material content in products for Computerco is ensuring the supply of high quality recycled plastics. These are needed to ensure the technical performance of computers. A similar barrier in regard to the quality of recycled plastic material was also identified in Toolco. One barrier for using recycled plastic material is that the brand colour of the plastic casing cannot be recreated by using recycled materials. The company is currently experimenting different processes and materials, with the aim of increasing the amount of recycled plastics in the tools.

The supply chain barriers are related to the identified barriers regarding ineffective waste and recycling policies. In the case of Windco, turbine operators are required by law to build capital reserves during the turbine lifetime to ensure proper decommissioning and recycling. Nevertheless, waste laws can inhibit SCC. In the Computerco case, one barrier for reverse logistics and repair activities was the difficulty of cross-border transports of waste electronics. An additional regulatory barrier in the Windco case is the phasing out of government subsidy mechanisms in Germany. For all wind turbines commissioned by December 31, 2000, subsidies expired at the end of 2020. This means that beyond this point, product-life extension has to be economically viable for customers even without the support of government subsidies (Quentin, Sudhaus and Endell, 2018). In addition, a lack of governmental support was identified as a barrier in the Toolco case:

"There is no tangible business case right now. At some point, it will have to be some form of regulation. We have seen in the past that regulation around silica dust and hand tool vibration really had an impact on the market. But we need that socio-political drive to push this and create the customer need that we can then tap into." – Toolco, Marketing Director (Int4)

Table 4-7 Enabling and inhibiting effect of external contextual factors

External Contextual Factors	Computerco			Toolco			Windco		
	PO	UO	Effect/Explanation	PO	UO	Effect/Explanation	PO	RO	Effect/Explanation
MARKET									
Increased environmental awareness of customers	x	x	**Enabler –Slowing & Closing**: Creates need for CE-related services, such as refurbishment or recycling.						
<u>New factor:</u> Price sensitivity of customer							x	x	**Enabler - Slowing**: Downward pressure on price enables Windco to compete through refurbishment services.
Speed of industry innovation cycles				x		**Barrier - Slowing**: Innovations around cordless tools create need in the market for new tools, make it more attractive for customers to upgrade to new equipment.		x	**Barrier - Slowing**: Shortening product lifecycles make it more attractive for customers to upgrade to larger turbines. Limit lifetime extension opportunities.
Lack of customer acceptance for circular products or business models		x	**Barrier - Slowing & Closing**: Especially public sector customers struggle with changing procurement processes to lease products over buying them outright.	x		**Barrier - Slowing**: Customers are poor in sending tools for repair. Will buy new products instead.	x	x	**Barrier - Slowing**: High costs and low revenues can make lifetime extension business case difficult for Windco customers
				x	x	**Barrier - Slowing**: Product quality & durability less important market differentiator in the UK, compared to other geographies, such as Sweden.			
SUPPLY CHAIN									
Suitable partners available									
Open collaboration and communication practices									
<u>New factor:</u> Vertical integration				x	x	**Enabler - Slowing & Closing**: Incentivises Toolco to ensure the		x	**Enabler - Slowing**: Allows Windco to make

External Contextual Factors	Computerco			Toolco			Windco		
	PO	UO	Effect/Explanation	PO	UO	Effect/Explanation	PO	RO	Effect/Explanation
						repairability and durability of tools as well as seek opportunities to capture value, such as component refurbishment.			hardware/software upgrades that make turbine more reliable or easier to maintain.
<u>New factor:</u> Competitive issues with other supply chain partners					x	**Barrier - Slowing**: Innovation towards result-oriented PSSs and potentially higher levels of slowing prevented, since Toolco does not want to compete with its tool hire customers.			
Lack of infrastructure to handle returns/wastes (e.g., recycling networks)									
Lack of supply network support (e.g., suitable partners)	x	x	**Barrier - Closing**: Lack of supply of high quality recycled materials, make it difficult to increase recycled content in products.						
REGULATORY									
Supportive regulations, taxation, subsidies							x	x	**Enabler - Closing**: Customers required by law to build capital reserves for decommissioning and recycling.
				x	x	**Barrier - Slowing & Closing:** Lack of regulation to create need in the construction industry for circular products or business models.	x	x	**Barrier - Slowing**: Phase out of government subsidies make a customer's business case for lifetime extension more difficult.
Ineffective waste/ recycling regulations	x	x	**Barrier - Closing**: Difficulty of managing waste logistics in Europe due to regulatory						

External Contextual Factors	Computerco			Toolco			Windco		
	PO	UO	Effect/Explanation	PO	UO	Effect/Explanation	PO	RO	Effect/Explanation
			restrictions on cross-border transports.						
Policies that promote material consumption over services									
Lacking quality standards (e.g. for refurbished products)									

4.5 Discussion

The conceptual framework (Figure 4-1) hypothesised that the PSSs types differed in their contribution to SCC due to differing levels of manufacturer-customer integration. The findings from this theory-testing case study show that PSSs have mixed contributions to the slowing and closing of resource loops. Based on the conceptual framework as well as the findings from this multiple-case study, four key propositions are made in the following subsections.

4.5.1 Contribution of PSSs to SCC: Context matters

According to Yang et al. (2018) different types of PSSs are associated with distinct SCC signatures. Specifically, they postulate that result-oriented PSSs have the highest degree of SCC, followed by use-oriented PSSs and product-oriented PSSs. According to them, result-oriented PSSs and use-oriented are the most well suited for SCC because product ownership is retained (Yang et al., 2018). The findings from this case study elaborate on this assertion.

The PSS classification in this study supports the notion that result-oriented PSSs have the highest potential for SCC, followed by use-oriented and product-oriented. In the product-oriented PSS, the customer was responsible for the majority of the product's use phase with only marginal manufacturer support, such as annual inspections or end-of-life pick up and recycling services. As expected, these were very much oriented and focused on the manufacturer supporting the customer's use of the product. In comparison, the use-oriented PSSs in the Computerco and Toolco cases saw a change in product ownership as the main difference between the product-oriented and use-oriented, which helped ensure product return at end-of-use.

Contrary to classification of result-oriented PSSs (Gaiardelli et al., 2014; Tukker, 2004), Windco did not retain product ownership in the result-oriented PSS. This is, however, not uncommon in machinery and equipment sectors, where project finance is provided by banks or financial services providers and ownership is retained by special purpose vehicles (Hypko, Tilebein and Gleich, 2010). While

product ownership was not retained by Windco, the result-oriented PSS still provided the manufacturer with a performance incentive to achieve availability outcomes during the turbine lifetime. In addition, they had the decision-making power over the planning and operation of maintenance services. The findings support the notion of Yang et al. (2018) that use-oriented and result-oriented PSSs have the highest potential for SCC.

Nevertheless, the potential is not always realised. In the case of Toolco there was no improvement in the slowing of resource loops, since tools were decommissioned and recycled upon return from the use-oriented PSS instead of being refurbished. For Windco, there was no improvement in the closing of resource loops due to the lack of recycling contribution stemming from the long lifetime nature of wind turbines. Nevertheless, while the recycling contribution is not necessarily higher in result-oriented PSSs compared to product-oriented PSSs, there will likely still be a high degree of resource loop closure, due to the strict regulations around turbine recycling at end-of-life. Overall, the findings from the case study suggest that PSS types do not have a "distinct circularity signature" (Yang et al., 2018, p.506). Instead, as the analysis of enablers and barriers in this paper shows, the role of the internal and external business context affects SCC outcomes in PSSs. This leads to the first proposition:

Proposition 1: *The contribution of PSSs to SCC is not only dependent on the PSS type, but also on the presence of enablers and barriers in the internal and external business context.*

4.5.2 The inhibiting effect of organisational linear lock-in

The analysis points to the inhibiting effect of organisational linear lock-in. This describes a prevailing linear mind-set and structure in companies, which expresses itself in a hesitancy and resistance to increasing SCC (Bressanelli, Perona and Saccani, 2019). In its use-oriented PSS, Toolco recovered a vast majority of its used tools from customers. Even though the products were of a high quality, durable and in many cases still usable, Toolco did not refurbish, but instead recycled them. This contradicts CE principles of keeping products and materials at highest utility and value at all times (Ellen MacArthur Foundation,

2013). The inconsistency with CE principles can be attributed to the company's underlying linear business logic, focused on product innovation and increasing new product sales. This inhibited a successful transition to higher levels of SCC, in particular to slowing of resource loops.

This finding fills an empirical gap in regard to the implications of PSSs on the slowing of resource loops (Hofmann, 2019; Merli, Preziosi and Acampora, 2018). In addition, they counter previous empirical findings highlighting the SCC benefits of use-oriented PSSs (Matschewsky, 2019; Yang et al., 2018). Overall, the findings show that while use-oriented PSSs contribute to a closing of resource loops, potential limitations in regard to slowing can be attributed to an organisational linear lock-in. In particular, refurbishment can challenge a company's existing value proposition focused on product innovation and sales. This leads to the second proposition:

Proposition 2: *An organisational linear lock-in is a barrier to the contribution of use-oriented PSSs to a slowing of resource loops, since it inhibits refurbishment.*

4.5.3 Internal environmental orientation as a prerequisite for high levels of slowing in use-oriented PSSs

The findings also elaborate on the role that a firm's pro-environmental culture and sustainability strategy have in enabling the contribution of PSSs to SCC (Kühl et al., 2019). The two organisational enablers, pro-environmental culture and integration of CE into a firm's strategy and goals, correspond to a firm's internal environmental orientation; a firm's internal environmental values as well as its commitment to environmental protection (Banerjee, 2001).

Environmental protection and CE are deeply embedded in Computerco's strategy and guided the innovation of its PSSs and supply chains. In particular, the planned upgrade to the use-oriented PSS would significantly increase the slowing and closing of resource loops in comparison to the current use-oriented and product-oriented PSSs. In this case, the continuous improvement and innovation of the contribution of PSSs to SCC was enabled by a strong internal environmental orientation.

Toolco on the other hand did not have a comparable environmental orientation, evidenced by the ongoing environmental strategy implementation process. Nevertheless, the company's PSSs still contributed to SCC, for example through the design of durable products, by conducting tool repairs, as well as through recycling in the use-oriented PSS. This is consistent with previous findings that show the potential contribution of use-oriented PSSs to SCC in manufacturing firms that are not environmentally-oriented (Matschewsky, 2019). Compared to Computerco, however, Toolco was unable to adopt product refurbishment in the design of its PSSs, which limited the potential contribution of its PSSs in particular to a slowing of resource loops. The findings show that while internal environmental orientation is not necessary for the contribution of PSSs to SCC *per se*, it enables high degrees of resource loop slowing in use-oriented PSSs, in particular through refurbishment. This leads to the third proposition:

Proposition 3: *A strong internal environmental orientation enables the contribution of use-oriented PSSs to a slowing of resource loops, by enabling refurbishment.*

4.5.4 The inhibiting effect of accelerating industry innovation cycles

The findings elaborate on the current understanding of the inhibiting effect of industry innovation cycles by highlighting the inhibiting role of accelerating industry innovation cycles in result-oriented PSSs. Result-oriented PSSs are suggested as a way forward to overcome shortening product innovation cycles, since they focus on providing outcomes or results and not specific products (Hofmann, 2019; Tukker, 2015).

The Windco case showed that in industries with shortening innovation cycles and significant product technology improvements, result-oriented PSSs may be inhibited in their ability to slow resource loops. In its result-oriented PSS, Windco relied on a number of CE enablers to reduce the customer's total cost of ownership, such as circular product design, digital technologies as well as optimised maintenance and service operations. Nevertheless, the customer's decision to extend turbine lifetime ultimately depended on the business case. In

many instances, it was financially favourable to upgrade to a larger wind turbine instead of extending the lifetime of the existing one, regardless of cost efficiency provided by Windco's result-oriented PSS. This is the first empirical evidence to show that in capital equipment contexts, in which there are significant technology improvements, shortening innovation cycles can inhibit the slowing of resource loops in result-oriented PSSs, since it inhibits the initial lifetime. This leads to the fourth proposition:

Proposition 4: *Accelerating industry innovation cycles are a barrier to the contribution of result-oriented PSSs to slowing resource loops, since they inhibit a customer's business case for initial lifetime extension.*

4.5.5 Empirically informed framework

Drawing together these propositions as well as the findings from the results, this study now proposes an updated conceptual framework of SCC in PSSs (Figure 4-3). The framework provides an overview of the empirically validated enablers and barriers of slowing and closing across the different PSSs.

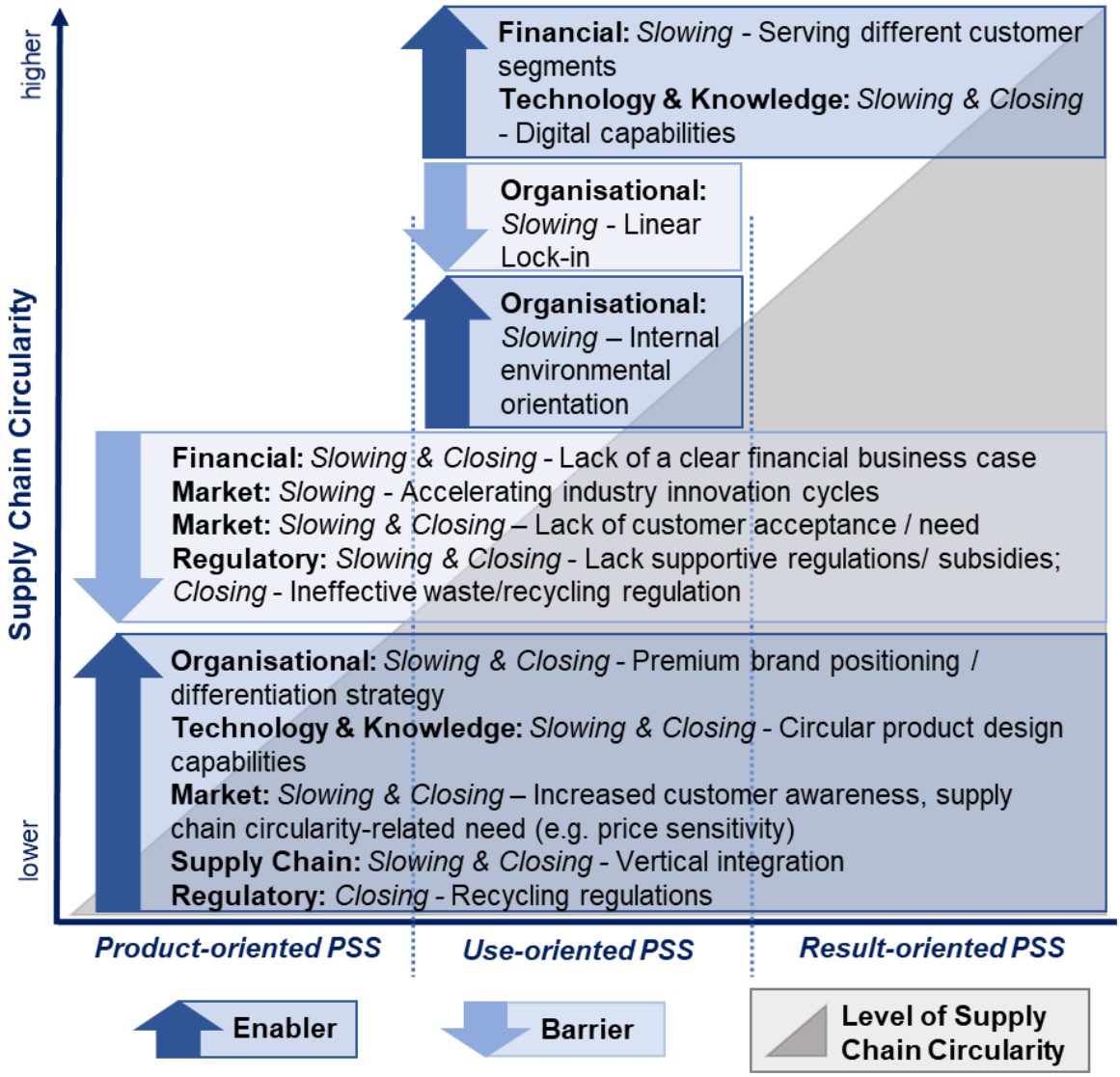

Figure 4-3 Empirically informed framework of PSSs contribution to SCC

4.6 Conclusion

4.6.1 Theoretical contributions

This study set out to test the assumption found in the literature that PSSs contribute to SCC. It aimed to answer two research questions:

1) How do product-service systems contribute to SCC?
2) What internal and external contextual factors enable or inhibit the contribution of PSSs to SCC?

In regard to the first research question, this study elaborates on the theoretical understanding regarding the contribution of PSSs to SCC (Yang et al., 2018). It confirms the findings of Yang et al. (2018) that show an overarching contribution of PSSs to SCC. Nevertheless, the findings challenge an implicit assumption that result-oriented PSSs inherently result in the highest SCC outcomes, followed by use-oriented and finally product-oriented PSSs (Yang et al., 2018). Instead, SCC outcomes not only depend on the PSS type, but also on the presence of enablers and barriers in the internal and external business environment.

In regard to the second research question, this paper investigates the role of contextual factors in inhibiting and enabling SCC outcomes in PSSs more closely. This was previously considered a gap in the literature (Kühl et al., 2019; Lüdeke-Freund, Gold and Bocken, 2019; Zeeuw van der Laan and Aurisicchio, 2020). The study puts forward an empirically validated framework of SCC in PSSs as well as a list of empirically validated enablers and barriers. In particular, it highlights the enabling effect of internal environmental orientation and the inhibiting role of organisational linear lock-in and accelerating industry innovation cycles. Moreover, this study contributes to the understanding of the effect of these enablers and barriers, by showing how their effect differs across PSSs and with respect to the slowing and closing of resource loops.

Furthermore, this paper contributes empirical evidence to important theoretical work underway in the CE literature about the implications of PSSs on the slowing of resource loops (Hofmann, 2019; Merli, Preziosi and Acampora, 2018). The findings from this paper suggest that contrary to expectation, use-oriented and result-oriented PSSs may not result in a significant improvement in the slowing of resource loops in comparison to product-oriented PSSs. In particular, the detrimental effects of organisational linear lock-in, product cannibalisation risks and accelerating innovation cycles pose a large barrier for the implementation of lifetime extension as well as refurbishment activities in PSSs.

4.6.2 Managerial implications

This study provides managers and policy-makers with a commentary on the current implementation of PSSs and their contribution to SCC.

Firstly, it shows that PSSs do not necessarily result in higher SCC outcomes. Implementing firms are limited by a lack of understanding of CE or a company culture that is unwilling to apply CE principles as an underlying innovation framework from design to delivery of PSS.

Secondly, this study provides managers with a framework of potential enablers and barriers that manufacturing firms can use to analyse their own internal and external context. Moreover, managers should collaborate with academia and other non-business actors to develop safe spaces to allow for innovative use- and result-oriented PSSs that slow and close resource loops, especially in regard to refurbishment.

Thirdly, this study also has implications for policy-makers. The findings from the case studies show that there are still significant barriers for SCC, particularly for extending product lifetimes as well as refurbishment. Policy-makers should work with industry associations and academics to devise a set of incentives that encourage manufacturing firms to transition to innovative PSSs that help to slow resource loops.

4.6.3 Limitations and further research

There are certain limitations that need to be considered when interpreting the findings. These limitations provide opportunities for further research.

Firstly, this study relied on purposefully chosen cases, which may limit the external validity of the findings. This study was limited to three large multinational firms that operate in a variety of different business-to-business environments. Instead of statistical generalisation, this study aimed for a theoretical generalisation of findings (Yin, 2018). This cross-case comparison was intended to increase the generalisability of the findings (Eisenhardt, 1989). Even though

they are all leading examples of PSS implementation, they may not necessarily be archetypal for all manufacturing firms that offer PSSs.

This research took a focal firm perspective to test the tenets of the NRBV in regard to SCC implications of PSSs. As a result, it does not explore the activities of customers or other actors in the value network and their role in creating SCC outcomes. Future research could expand on this focal firm perspective and adopt a dyadic or a network perspective.

Thirdly, the findings enable the induction of four propositions as well as an empirical framework, which elaborated on the relationship between PSSs and SCC. Future research could test the propositions, for example, through other research methodologies, such as surveys. In addition, to extend and further develop the framework, future research should prioritise the implications of PSSs on the slowing of resource loops, for example through case study research.

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5 Conclusion

5.1 Review of research objectives and findings

This section presents the results of the PhD research on the relationship between product-service systems (PSSs) and supply chain circularity (SCC). It does so in a paper-format whereby Chapters 2 to 4 each represent a standalone paper. The overarching research question was: *How do PSSs relate to SCC*? This PhD thesis has three primary research objectives:

1) To systematically review the relevant literature to identify what is known about the relationship between PSSs and SCC and about the enabling and inhibiting effect that contextual factors have on this relationship;
2) To empirically investigate the relationship between PSSs and SCC;
3) To empirically investigate the enabling and inhibiting effect that contextual factors have on the relationship between PSSs and SCC.

Table 5-1 summarises the relevant research findings regarding the initial research objectives. This PhD thesis is based on a concurrent or a complementary mixed methods research design (Creswell and Plano Clark, 2018; Plano Clark and Ivankova, 2017). Here, qualitative and quantitative research approaches are conducted concurrently with the purpose of producing a more complete and comprehensive understanding of the phenomenon under study (Plano Clark and Ivankova, 2017).

Table 5-1 Mapping of relevant findings to research objectives

Research Objectives	Findings	Chapter
1) To systematically review the relevant literature to identify what is known about the relationship between PSSs and SCC and about the enabling and inhibiting effect of contextual factors have on this relationship.	• Identifies implementation of fifteen SCC practices that slow, close, and narrow resource loops across empirical papers of PSS implementation.	Chapter 2
	• Establishes a conceptual map that posits that the slowing, closing, and narrowing of resource loops is highest in result-oriented PSSs, followed by use-oriented and product-oriented PSSs.	Chapter 2
	• Proposes that PSSs mainly contribute to SCC through a slowing, followed by a closing and finally a narrowing of resource loops.	Chapter 2
	• Identifies eleven contextual factors that can enable and inhibit the degree to which PSSs affect SCC. It categorises them across six categories: 1) Economic attractiveness of SCC; 2) Firm sustainability strategy; 3) Policy and societal environment; 4) Product category; 5) Supply chain relationships; 6) Technology.	Chapter 2
	• Highlights the importance of firm sustainability strategy as an enabling factor.	Chapter 2
2) To empirically investigate the relationship between PSSs and SCC.	• Shows that product-oriented PSSs contribute to the implementation of practices that slow resource loops, use-oriented PSSs to those that close resource loops, and result-oriented PSSs to those that slow, close, and narrow resource loops.	Chapter 3
	• The relationship between PSSs and SCC does not only depend on the PSS type, but also on the presence of enablers and barriers in the internal and external context.	Chapter 4
	• Use-oriented PSSs may not result in a slowing of resource loops through refurbishment, compared to product-oriented PSSs.	Chapter 4
	• Result-oriented PSSs may not result in a closing of resource loops, compared to product-oriented PSSs.	Chapter 4
3) To empirically investigate the enabling and inhibiting role that contextual factors have on this relationship.	• Firm size does not moderate the relationship between PSSs and SCC practice implementation.	Chapter 3
	• Internal environmental orientation does not moderate the relationship between PSSs and SCC practice implementation.	Chapter 3
	• Develops an empirically validated framework of nineteen enablers and barriers for the slowing and closing of resource loops across the different PSS types.	Chapter 4
	• Organisational linear lock-in inhibits the slowing of resource loops in use-oriented PSSs, by inhibiting refurbishment.	Chapter 4
	• The speed of industry innovation cycles inhibits the slowing of resource loops in result-oriented PSSs, by inhibiting initial lifetime extension and refurbishment.	Chapter 4
	• Internal environmental orientation contributes to the slowing of resource loops in use-oriented PSSs, by enabling refurbishment.	Chapter 4

The first research objective is addressed in Chapter 2. Based on a review of empirical evidence of PSS implementation, a conceptual map is established that posits that the slowing, closing, and narrowing of resource loops is highest in result-oriented PSSs, followed by use-oriented and finally product-oriented PSSs. It proposes that the main contribution stems from an increased slowing, followed by a closing, and finally a narrowing resource loops. Moreover, the model also identifies and categorises six contextual factors, which include: 1) Economic attractiveness of SCC; 2) Firm sustainability strategy; 3) Policy and societal environment; 4) Product category; 5) Supply chain relationships; 6) Technology. The model is deduced from the literature. The review identifies and categorises the various contextual factors that may affect how PSSs contribute to SCC. This paper contributes to the literature, by systematically synthesising the relationship between PSSs and SCC.

The second research objective is addressed in both Chapters 3 and 4. In Chapter 3, the findings show that product-oriented PSSs contribute to the slowing of resource loops, use-oriented PSSs to the closing of resource loops, and result-oriented PSSs to the slowing, closing, and narrowing of resource loops. In Chapter 4, the findings show that in comparison to product-oriented PSSs, use-oriented and result-oriented PSSs do not necessarily contribute to the slowing and closing of resource loops. The findings suggest that PSS types do not have a "distinct circularity signature" (Yang et al., 2018, p.506), but that SCC outcomes depend on the presence of enablers and barriers in the firm context.

The third research objective is also addressed in both empirical chapters. The survey contributes to the third research objective, by testing the moderating effects of firm size and internal environmental orientation. The choice of moderators emerged from the results of the SLR in Chapter 2. It finds that firm size and internal environmental orientation do not moderate this relationship. One explanation for the insignificance of firm size is that smaller firms may have a higher capacity to learn, develop new knowledge and embrace new ideas, such as CE (Leal-Rodríguez et al., 2015). Empirically, this is supported by the examples of SMEs and start-ups experimenting with circular business models

(Corvellec and Stål, 2017; Linder and Williander, 2017). In regard to internal environmental orientation, SCC practice implementation in PSSs may ultimately be determined by more pragmatic reasons, such as cost reduction or competitiveness (Rosa, Sassanelli and Terzi, 2019).

Chapter 4 provides empirical evidence of nineteen enablers and barriers and how they affect the slowing and closing of resource loops across the different PSS types. These contextual factors are categorised into organisational, financial, technology and knowledge, market, supply chain, and institutional and regulatory factors. It induces four propositions that highlight the enabling and inhibiting effect of contextual factors. These highlight in particular the enabling and inhibiting effects of organisational factors on the contribution of use-oriented PSSs to the slowing of resource loops through refurbishment.

5.2 Contributions to theory and practice

Table 5-2 depicts each paper's theoretical, methodological, and practical contributions. The key thematic contributions are described in more detail in sections 5.2.1 to 5.2.3.

Table 5-2 Research contributions

Article Title	Theoretical contributions	Methodological / Practical contributions
How does servitization affect supply chain circularity? – A systematic literature review (Chapter 2 / Paper 1)	• Systematic synthesis of the relationship between PSSs and SCC • Develops a conceptual map that suggest that PSSs contribute to SCC • Defines six categories of contextual factors that enable and relationship between PSSs and SCC • Induces research propositions from the case study findings • Refines SCC concept, by defining 15 practices and linking them to the three SCC modes (slowing, closing, and narrowing)	• **Practical:** Provides a framework of relevant SCC practices; Identifies potential enablers and barriers for SCC in PSSs
Product-service systems and circular supply chain practices: The moderating effect of firm size and internal environmental	• Shows that product-oriented PSSs contribute to the slowing, use-oriented to the closing, and result-oriented PSSs to the slowing, closing and narrowing of resource loops. • Shows that firm size and internal environmental orientation do not	• **Methodological:** Develops and validates survey items for SCC (slowing, closing, narrowing) • **Practical:** Offers survey items as a self-diagnostic

Article Title	Theoretical contributions	Methodological / Practical contributions
orientation (Chapter 3 / Paper 2)	moderate the relationship between PSSs and SCC practice implementation.	tool to enable businesses to benchmark and assess SCC practice implementation.
Supply chain circularity implications of product-service systems: A multi-case study (Chapter 4 / Paper 3)	• Evidences that the contribution of PSSs is not only dependent on the PSS type, but also on the presence of enablers and barriers in the firm context. • Induces four propositions that highlight the enabling and inhibiting effect of contextual factors, in particular of organisational factors on the contribution of use-oriented PSSs to the slowing of resource loops • Develops an empirically validated conceptual framework that accounts for the effect of nineteen enablers and barriers on the contribution of the different PSSs on the slowing and closing of resource loops.	• **Practical:** Offers an empirically validated framework of enablers and barriers

5.2.1 Theoretical contributions

This section describes the three key theoretical contributions of this PhD thesis to the CE, PSS and SCM literature. Firstly, it elaborates on the relationship between PSSs and SCC, by showing the limitations of use-oriented PSSs in regard to slowing of resource use. Secondly, it extends and elaborates on the effect of contextual factors, by developing an empirically validated framework of contextual factors. Thirdly, it contributes to the conceptual development of SCC, by defining specific practices associated with the slowing, closing, and narrowing of resource loops and offering an initial theory of how the transition to SCC occurs in manufacturing firms.

5.2.1.1 Relationship between PSSs and SCC: The limitations of use-oriented PSSs in slowing resource loops

This PhD thesis tests the assumption underlying the PSS and CE literature, that manufacturers that offer PSSs will maximise resource efficiency and optimise resource utilisation to increase their profitability (Hofmann, 2019; Tukker, 2015), hence contributing to SCC. As a result, it addresses the core of the CE's business driven approach and the belief that business and innovation can catalyse

economic and environmental win-wins (Calisto Friant, Vermeulen and Salomone, 2020).

Chapter 3 conducts a survey to empirically test the conceptual map developed in Chapter 2. It shows that product-oriented PSSs contribute to the implementation of practices that slow resource loops, use-oriented PSSs to the implementation of practices that close resource loops, and result-oriented PSSs to practices that slow, close and narrow of resource loops. The results from Chapter 3 show that use-oriented PSSs do not lead to an implementation of practices associated with the slowing of resource loops. This provides initial empirical evidence to the conjecture that use-oriented PSSs are limited in their potential for slowing resource loops (Hofmann, 2019).

Chapter 4 independently corroborates the findings from Chapter 3 regarding the limitations of use-oriented PSSs in slowing resource loops. Moreover, it extends these by identifying how and why use-oriented PSSs may not always contribute to a slowing of resource loops. The limitation of use-oriented PSSs can be attributed in particular to the difficulty and complexity of implementing product refurbishment. As mentioned in Section 5.2.1.2, organisational factors were identified as the most relevant enablers and barriers for slowing in use-oriented PSSs. This can be explained primarily by organisational barriers, such as organisational linear lock-in or a lacking internal environmental orientation. As a result, this paper contributes empirical evidence to important theoretical work underway in the CE literature about the implications of PSSs on the slowing of resource loops (Hofmann, 2019; Merli, Preziosi and Acampora, 2018). In particular, the detrimental effects of organisational linear lock-in and the associated product cannibalisation pose a large barrier for the slowing of resource loops through refurbishment in use-oriented PSSs. Overall, Chapter 4 contributes to theory development, through falsification, so by identifying cases in which the deduced hypotheses were not supported (Tsang, 2014).

In summary, this PhD provides the first in-depth empirical investigation on the limitations of use-oriented PSSs in regard to slowing, particularly refurbishment. Contrary to Yang et al., (2018) and to the practitioner literature (Ellen MacArthur

Foundation, 2013; Lacy and Rutqvist, 2015), which consider use-oriented PSSs such as leasing crucial elements in the transition to a CE, this PhD takes a more sceptical stance (Hofmann, 2019). The empirical evidence in this PhD shows that in practice, use-oriented PSSs may merely be linear business models in circular disguise.

5.2.1.2 Empirically validated contextual factors: Enablers and barriers across PSSs and the slowing and closing of resource loops

The introduction also highlighted the existing gap around the effect of contextual factors in enabling and inhibiting the relationship between PSSs and SCC (Lüdeke-Freund, Gold and Bocken, 2019). Apart from very few exceptions (Vermunt et al., 2019), the literature on SCC enablers and barriers does not focus specifically on PSSs, but on other types of business models associated with CE (Guldmann and Huulgaard, 2020; Tura et al., 2019). This research fills this gap, by specifying how their effect differs across PSS types and across the slowing and closing of resource loops. In particular, the analysis highlights the enabling and inhibiting effect that organisational factors have on the slowing of resource loops in use-oriented PSSs.

Chapter 2 develops an initial list of contextual factors through an SLR. Chapter 4 extends existing classifications of contextual factors (Kühl et al., 2019; Tura et al., 2019; Vermunt et al., 2019), by providing empirical evidence on how their effect differs across PSSs and the slowing and closing of resource loops. These findings are presented in a framework and list of nineteen enablers and barriers for the contribution of different PSS types to a slowing and closing of resource loops. Among these, the research highlights the enabling and inhibiting role of organisational factors. Organisational factors especially affected the contribution of use-oriented PSSs to a slowing of resource loops through refurbishment. On one hand, a strong internal environmental orientation enabled the companies to innovate their PSSs and supply chains towards circularity, for example, by cascading products along multiple lifecycles. On the other hand, an organisational linear lock-in and concerns over refurbished tools cannibalising

new product sales or undermining a premium brand image, inhibited the slowing of resource loops.

The empirically validated framework of contextual factors confirms previous claims on the enabling and inhibiting role that organisational factors play in SCC (Kirchherr et al., 2018; Rizos et al. 2016). It also extends these, by highlighting the effects on slowing in use-oriented PSSs, particularly through refurbishment. It fills an empirical gap, by not only highlighting the challenges of use-oriented PSSs in the slowing of resource loops, but also helping to explain why (Hofmann, 2019; Merli, Preziosi and Acampora, 2018).

Overall, this PhD underscores the role that contextual factors play in the contribution of PSSs to SCC. Against this backdrop, this thesis also elaborates on the aforementioned potential ability for business and innovation to create economic and environmental win-wins (Calisto Friant, Vermeulen and Salomone, 2020). Ultimately, the case study findings show that PSSs by themselves are not guarantees for SCC. PSSs need to be regarded in the context within they operate and do not inherently result in increased SCC. It follows that a technocentric approach to CE that solely trusts business and innovation to lead the transition to SCC, will likely not result in the desired economic and environmental benefits (Calisto Friant, Vermeulen and Salomone, 2020; Matschewsky, 2019). Ultimately, PSSs need to be embedded in an enabling system that creates the necessary organisational, economic, regulatory, and cultural environment for this concept to contribute to SCC.

5.2.1.3 SCC: Advancing the conceptual understanding

Finally, this study contributes to the wider SCM and the CE literature, by elaborating and refining the conceptual understanding of SCC. Firstly, it extends previous classifications, by developing an empirically validated list of supply chain practices associated with the slowing, closing, and narrowing of resource loops. In Chapter 2, a first attempt is made at extending and elaborating the understanding of SCC. Through an SLR, it describes the three relevant modes, slowing, closing, and narrowing and linking them to 15 specific practices as well as identifying performance measures. Chapter 3 builds and extends on this

foundation. Through the series of expert interviews as well as a survey of 206 manufacturing firms in the UK, a refined and empirically validated list of 19 practices associated with the slowing, closing, and narrowing of resource loops is developed. The definition of SCC practices contributes to the development of this concept. It extends previous work focused on defining and demarcating it from other related narratives in the SCM literature, such as sustainable, green or closed-loop supply chains (De Angelis, Howard and Miemczyk, 2018; Batista et al., 2018). This provides a foundation for benchmarking SCC, thereby contributing to work currently underway on the measurement of SCC for manufacturing firms (Garza-Reyes et al., 2018).

Secondly, the findings from Chapter 3 provide a first attempt at theorising how the transition to SCC occurs at firm-level (Frishammar and Parida, 2019; van Loon and Van Wassenhove, 2020). As previously mentioned, it shows that product-oriented PSSs contribute to the implementation of practices that slow resource loops, use-oriented PSSs to the implementation of practices that close resource loops, and result-oriented PSSs to practices that slow, close and narrow resource loops. This suggests that manufacturing firms undergoing the servitization process will prioritise different aspects and practices associated with SCC. In particular, at the beginning of the servitization journey, when manufacturers focus on developing product-oriented PSSs (Sousa and da Silveira, 2017), they will focus on implementing practices that slow resource loops, but as they increasingly add more complex services, such as use-oriented and result-oriented PSSs, they will also implement practices that close and narrow resource loops.

5.2.2 Methodological contributions

In Chapter 3, a methodological contribution is made through the development of measurement items for SCC practices. Firstly, this PhD thesis extends previous survey items for SCC practices (Masi et al., 2018; Zhu, Geng and Lai, 2010), by aligning the construct with the theoretical dimensions of SCC instead of adopting dimensions and items that were developed for other sustainable supply chain narratives. Previous studies that focused on SCC practices used items that were

developed for other sustainable supply chain narratives, such as green or sustainable supply chains (Masi et al., 2018; Zhu, Geng and Lai, 2010). This is important for the content validity of the construct, since these narratives are related, but different from SCC (Batista et al., 2018). Secondly, it provides a more robust classification of practices than Masi et al. (2018), by establishing the construct's validity and reliability. The results indicate good indicator loadings for the practices associated with narrowing but suggest that adapting the items associated with slowing and closing may help improve some of the weaker outer loadings (<0.70). These dimensions and measurement items provide a methodological contribution, by offering researchers and practitioners a framework for assessing the implementation of SCC practices.

5.2.3 Practical contributions

This study also makes significant practical contributions and offers numerous implications for manufacturing firms engaged with PSSs and CE:

- Firstly, this research can particularly help machinery and equipment manufacturing firms in assessing and benchmarking the current state of SCC practice implementation in their organisation as well as identifying areas for improvement. It presents firms with a framework of nineteen practices associated with the slowing, closing and narrowing of resource use. This validated set of measurement items can guide manufacturers in increasing the circularity of their supply chains and to potentially reap the associated economic and environmental benefits (Rosa, Sassanelli and Terzi, 2019; Yang and Evans, 2019).
- Secondly, this research provides managers in machinery and equipment manufacturing firms in the UK with a guideline of how they should develop SCC during their servitization journey. When embarking on the journey towards services and developing the initial product-oriented PSSs, manufacturing firms should first focus on the implementation of practices that slow resource loops. As they add more complex offerings to their service mix, such as use-oriented and result-oriented PSSs, they are recommended to

also implement practices associated with the closing and narrowing of resource loops.

- Thirdly, this research provides managers with a framework and list nineteen internal and external enablers and barriers for the contribution of different PSS types to a slowing and closing of resource loops. Managers need to understand that there is no one-size-fits-all approach to PSS and SCC implementation. By distinguishing the effect between the PSS type as well as slowing or closing, it facilitates the identification of potential enablers or barriers. This will allow managers to develop suitable solutions.
- Fourthly, this study identifies several organisational challenges for slowing resource loops in use-oriented PSSs. Managers in firms that either already have or are planning to implement use-oriented PSSs are advised to collaborate with academia or consultants to develop CE as an innovation framework for their use-oriented PSSs, especially in regard to refurbishment. In doing so, organisations can adapt their perspective on value creation and identify new business opportunities to help increase competitive advantage (Rosa, Sassanelli and Terzi, 2019; Yang and Evans, 2019). One potential avenue is to strengthen the internal environmental orientation, for example, by embedding environmental aspects more strongly in the firm strategy or by introducing CE-related goals in each business unit.

This research also has implications for policy-makers. Given the potential contribution of PSSs to SCC, governments especially in the UK and in Europe should formulate policies that encourage manufacturing firms to embark on the servitization journey and to develop more complex use- and result-oriented PSSs.

- Firstly, the research provides policymakers with empirical evidence on the contribution of PSSs to SCC. Particularly the practitioner literature (Ellen MacArthur Foundation, 2013; Lacy and Rutqvist, 2015) considers use-oriented PSSs, such as leasing, crucial elements in the transition to a CE. This research shows that use-oriented PSSs, in particular, need to be seen critically regarding their contribution to a slowing of resource loops.

Governments need to clearly define a vision around CE that is focused on slowing resource loops and create an enabling regulatory framework for this. This can start with supporting the 'right for repair' of consumers and mandating companies to design products for longevity and repairability.

- Secondly, the results from the survey showed that result-oriented PSSs are not widely adopted in practice. Governments can provide the financial and regulatory support that encourage the uptake of these types of business models. One potential measure could be to reduce the value-added tax on labour intensive SCC practices, such as repair or refurbishment, thereby making services more financially attractive to manufacturers.
- Thirdly, policy-makers should encourage the development of trainings and courses to help educate managers in manufacturing firms about the potential opportunities associated with PSSs and increasing the SCC, particularly in regard to refurbishment.

5.3 Limitations

The study has several limitations that need to be taken into account. The SLR draws on a body of literature around circular PSS implementation, which is still nascent and currently emerging. At present, there are few empirical studies that focus specifically on the relationship between PSS and SCC. One possible explanation for the relative lack of identified practices that close and narrow resource loops is these practices are not directly related to the provision of service outcomes. Practices that slow resource loops on the other hand help ensure a product's functionality and are therefore critical to a successful service delivery. As a result, existing studies may have simply not focussed on aspects related to closing or narrowing.

The empirical studies concentrate only on firms in equipment and manufacturing industries in the UK and in Germany, due to the prevalence of PSSs in these types of industries. This can constrain the generalisability of the findings to other firm contexts. The survey responses in Chapter 3 were acquired through the use of a volunteer opt-in panel. Due to this non-probability approach to sampling, the

findings are limited to the sample and have limited statistical significance. Nevertheless, the use of non-probability sampling is suitable for exploratory research, such as this one (Daniel, 2012). In addition, the survey relies on the perceptions of survey respondents to elicit the insights, which could limit the validity of the results. In addition, since the survey relies on only one method for data collection, there is the risk of common method variance. However, the use of both Harman's single factor test (Podsakoff et al., 2003) as well as a full collinearity assessment employing the partial least squares method (Kock, 2015) show that this issue us not a concern.

The multiple-case study in Chapter 4 aimed for a theoretical generalisation of findings instead of statistical generalisation (Yin, 2018). The cross-case comparison was intended to increase the generalisability of the findings (Eisenhardt, 1989). Nevertheless, the study relied on purposefully chosen cases, which may limit the external validity of the findings. This study was limited to three large multinational firms in the UK and in Germany that operate in a variety of different business-to-business environments. Hence, care needs to be taken when generalising the findings to different business contexts. The case study research also took a focal firm perspective to test the tenets of the NRBV in regard to SCC implications of PSSs. As a result, it does not explore the activities of customers or other actors in the value network and their role in creating SCC outcomes.

5.4 Future research directions

There are a variety of future research avenues that emanate from this study:

1) Future research could adopt a longitudinal research design to investigate how a firm's servitization journey and development of different types of PSSs contributes to SCC over time. This would make it possible to capture the longitudinal dimension of this transition phenomenon and to further elaborate on the framework of contextual factors, by identifying further enablers and barriers for SCC at different stages in the servitization journey.

2) Future research could build on the findings of the case study paper, by testing the propositions that were developed. In particular, one promising research avenue is to study the implications of PSSs on the slowing of resource loops, in particular refurbishment more closely. Case study research could for example investigate the innovation process in companies to identify how companies develop profitable business models based on refurbishment and what internal and external factors affect the success of such innovations.

3) Future research can address some of the limitations of the empirical papers. The survey paper is constrained by the exploratory non-probability sampling approach. Future research is recommended to conduct a probability sampling approach to increase the statistical generalisability of the findings. Moreover, future research could study the phenomenon across different contexts to further elaborate on the findings, especially the framework of contextual factors. One promising avenue is to study the context of SMEs more closely. The results of the survey suggest that firm size does not moderate the relationship between PSSs and SCC practice implementation. Nevertheless, studies point to the unique difficulties and challenges faced by SMEs in the transition to SCC (Dey et al., 2020).

4) Future research could build on this focal firm perspective and to adopt a dyadic or network perspective to investigate the relationship between PSSs and SCC. This would make it possible to identify practices of different actors that contribute to the systemic circularity outcomes.

5) More research is needed to develop assessment methods and tools for SCC. Future studies can build on the SCC practices developed in this study to develop a qualitative and quantitative assessment tool for manufacturing firms. This research objective can be combined with the need for longitudinal research to develop a maturity model for SCC and identify how this develops over time.

This thesis investigates the relationship between PSSs and SCC. Each of the papers make a range of theoretical, methodological and practical contributions and provides a variety of opportunities for future research. Overall, it is hoped

that this initial research lays a foundation for others to build on and contributes to the successful transition from a linear to a circular economy.

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Glossary

This section defines the key terms employed in this PhD research (see Table A-1).

Table A-1 Glossary

Term	Definition
Circular economy	“a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. this can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling” (Geissdoerfer et al., 2017, p.766)
Circular supply chain	Circular supply chains slow, close, and narrow resource loops to increase competitive advantage as well as economic, environmental, and operational performance (Geissdoerfer et al., 2017, 2018)
Closing	“Through recycling, the loop between post-use and production is closed, resulting in a circular flow of resources.” (Bocken et al., 2016, p. 309)
Internal environmental orientation	Internal environmental orientation refers to managers' and employees' values and ethical standards in regard to environmental protection (Banerjee, 2002). It can be conceptualised as a pro-environmental culture that manifests itself in a firm’s mission statements, policies, procedures, and the training of employees (Banerjee, 2002; Chan et al., 2012)
Narrowing	“Resource efficiency or narrowing resource flows, aimed at using fewer resources per product.” (Bocken et al., 2016, p. 309)
Product-service-system	“Tangible products and intangible services designed and combined so that they jointly are capable of fulfilling specific customer needs” (Tukker, 2004, p. 246)
Slowing	“Through the design of long-life goods and product-life extension (i.e. service loops to extend a product’s life, for instance through repair, remanufacturing), the utilisation period of products is extended and/or intensified, resulting in a slowdown of the flow of resources.” (Bocken et al., 2016, p. 309)

Term	Definition
Supply Chain Circularity	The extent to which supply chains slow, closed, and narrow

APPENDICES

This section describes the methods used for the empirical research in Chapters 3 and 4 in more detail.

Appendix A – Survey

Dear Participant,

Thank you for supporting us by participating in this survey. The survey will require approximately **10 minutes** to complete. We are looking for a wide range of responses. Therefore, please try to provide your best guess and complete all questions, even if some of them are not in your area of expertise.

Please be aware that: Your participation is completely voluntary; You can withdraw or modify the information provided until May 2020, when the data will be analysed; Individual survey responses will be fully anonymous. Collected survey data will be stored securely on Cranfield University's encrypted repository and made available for re-use.

The study is part of 'Circ€uit', the Circular European Economy Innovative Training Network, an 'Horizon 2020' action funded by the European Commission (https://www.itncircuit.eu/). If you have any questions or would like to modify/withdraw your response, please feel free to contact me at c.kuhl@cranfield.ac.uk. Thank you in advance and your participation is greatly appreciated.

Sincerely yours,

Carl Kühl

SECTION A: ABOUT THE RESPONDENT

1. I have read the above information and voluntarily agree to participate in this survey.

A. Yes

B. No

2. Please specify the country in which you are currently employed:

A. England

B. Scotland

C. Wales

D. Northern Ireland

3. Please select the manufacturing industry that your company primarily belongs to:

A. Computers and office machinery

B. Consumer electronics

C. Measuring, testing, process control equipment

D. Irradiation, electromedical and electrotherapeutic equipment

E. Optical precision instruments

F. Electric motors, generators, batteries and transformers

G. Domestic appliances

H. Engines and turbines

J. Lifting and handling equipment

K. Power-driven hand tools

L. Agricultural and forestry machinery

M. Mining and earthmoving equipment

N. Machinery for food, beverage and tobacco processing

P. Machinery for paper and paperboard production

R. Other

Which of the following categories best describes your position?

A. Account Manager

B. Marketing/ Sales Manager

C. Logistics Manager

D. Operations Manager

E. Purchasing Manager

F. Supply Chain Manager

G. Project Manager

H. Research and Development Manager

I. Environment, Health, and Safety (EHS) Manager

J. Corporate Social Responsibility (CSR) Manager

K. Other (Please specify)

4. How long have you been working in the current industry? _____ year(s)

5. Please specify your company's number of employees:

A. <10

B. 10-49

C. 50-249

D. 250-5000

E. >5000

6. Please select the turnover your company had last year (in UK Pound Sterling):

A. < £1.8 million

B. £1.8 million - ≤ £9 million

C. > £9 million - ≤ £45 million

D. > £45 million - ≤ £223 million

E. > £223 million

SECTION B: SERVICE OFFERINGS

7. To what extent do you perceive that the following stand-alone services are offered alongside the products sold by your company? Please mark a number (Five-point scale: select N/A = not at all; 1 = to a very small extent; 2 = to a small extent; 3 = to a moderate extent; 4 = to a great extent; 5 = to a very great extent).

No.	Item	N/A	1	2	3	4	5
PO1	Installation/commissioning of products						
PO2	Provision of spare parts/consumables						
PO3	Maintenance and repair of products						
PO4	Helpdesk/customer support centre						

8. To what extent do you perceive that these services are offered by your company? Please mark a number (Five-point scale: select N/A = not at all; 1 = to a very small extent; 2 = to a small extent; 3 = to a moderate extent; 4 = to a great extent; 5 = to a very great extent).

No.	Item	N/A	1	2	3	4	5
UO1	Lease of products (service provider is responsible for repairs; long-term contract; single user)						
UO2	Rental of products (service provider is responsible for repairs; short-term contract; different sequential users)						
UO3	Pay-per-use (service provider gives customers access to products; customer only pays according to the level of use)						
RO1	Performance-based contract (service provider paid for delivering results to customer, not individual products or services; e.g. delivering holes-in-walls, not power drills and repairs)						
RO2	Outsourcing (service provider manages one or more non-core activities for the customer)						

SECTION C: CIRCULAR SUPPLY CHAIN PRACTICES

9. To what extent do you perceive that your company is implementing each of these circular supply chain practices? Please mark a number (Five-point scale: 1 = not considering it; 2 = planning to consider it; 3 =

considering it currently; 4 = initiating implementation; 5 = implementing successfully).

	No.	Item	1	2	3	4	5
Slowing	SLOW1	Design of products for durability					
	SLOW2	Design of products for ease of maintenance and repair					
	SLOW3	Design of products for future modification (adaptability or upgradability)					
	SLOW4	Design of products for refurbishment or remanufacturing					
	SLOW5	Collection of used products from customers for reuse or resale					
	SLOW6	Maintenance and repair of products					
	SLOW7	Collection of used products from customers for refurbishment or remanufacturing					
Closing	CLOS1	Design of products for recycling					
	CLOS2	Use of recycled materials in products					
	CLOS3	Collection of used products from customers for recycling					
	CLOS4	Recovery of components from used products for reuse in other products					
		To check your attention, please select ‘not considering it’ for this item					
	CLOS5	Transfer of wastes or by-products for reuse in another process					
Narrowing	NAR1	Design of products to reduce the consumption of material/energy during the use phase					
	NAR2	Design of product to reduce their weight					
	NAR3	Re-design of production processes to reduce the consumption of material/energy					
	NAR4	Supplier collaboration to reduce the consumption of material/energy					
	NAR5	Customer collaboration to reduce the consumption of material/energy					

SECTION D: INTERNAL ENVIRONMENTAL ORIENTATION

10. For each of the statements below, what is the role of environmental aspects in your company? Please mark a number (Five-point scale: 1 = strongly disagree; 2 = disagree; 3 = neutral; 4 = agree; 5 = strongly agree).

No.	Item	1	2	3	4	5
IEO1	The company makes a concerted effort to make every employee understand the importance of environmental preservation.					
IEO2	The company has a clear policy statement urging environmental awareness in every area.					
IEO3	Environmental preservation is a high-priority activity in the company.					
	The company clearly urges its employees to undertake actions against the environment.					
IEO4	Preserving the environment is a central corporate value.					

Thank you for your contribution, it is greatly appreciated!

Appendix B – Survey pilot study

B.1 Academic expert study

The purpose of this academic expert review was to provide feedback on the survey design, the formulations as well as the content of the items. The feedback of expert academics was particularly important for the development of the new circular supply chain practice items. Clear scale development is necessary to ensure that the scale includes all aspects included in the domain and is clear on what needs to be excluded. Potential risks are construct underrepresentation, when a construct is defined to narrowly, or too broadly defined constructs, which create construct-irrelevant variance (Netemeyer, Bearden and Sharma, 2012). As a result, the decision was made to check the content validity of the previously developed items. Content validity is defined as “the degree to which elements of an assessment instrument are relevant to and representative of the targeted construct for a particular assessment purpose” (Haynes, Richard and Kubany, 1995, p.238). Content validity should be assessed by at least five subject matter experts to ensure the confidence in the feedback given (Netemeyer, Bearden and Sharma, 2012). Table B-1 outlines the academic experts that were selected to assess the content validity of the items involved in the research.

B.1.1 Participants

The selection of these experts was based on whether they had relevant subject matter expertise in at least two of the three areas (SCM, CE, Servitization). The academic experts are not part of the research team. They were consulted in one-on-one interviews that lasted about 30 minutes each. The interviews were conducted in the first half of August 2019. The experts were first instructed on the purpose of the study, before being asked to provide feedback. The questions were intended to validate the previous scale development process. The questions were as follows: 1) Do you think that the items adequately reflect the constructs? Is there anything missing or included that should not be included? 2) Do you think that any of the items are unclear? 3) Are there any aspects that are missing?

Table B-1 Academic experts

Expert	Role	Background	Expertise
Academic 1	Lecturer *Cranfield School of Management (UK)*	Lecturer with research experience in SCM & in sustainable supply chain management, an area closely related to CE. Has also published on servitization.	SCM, Services, CE
Academic 2	Associate Professor *Cranfield School of Management (UK)]*	Associate professor in SCM with experience in SCM and sustainable/circular supply chain management.	SCM, CE
Academic 3	Associate Professor *Cranfield School of Management (UK)*	Associate professor with 20+ years of experience working in academia and industry. Has published on SCM, CE.	SCM, CE
Academic 4	Research Fellow *Cranfield School of Management (UK)*	4 years of experience in research on CE, Servitization, SCM. He has also gained 7+ years working for the mechanical engineering industry in Switzerland.	SCM, Services, CE
Academic 5	Lecturer *Cranfield School of Management (UK)*	Lecturer in SCM. Experience in researching servitization in UK manufacturing firms.	SCM, Services
Academic 6	Senior Lecturer *Cranfield School of Management (UK)*	Senior lecturer with 15+ years of industry experience as a senior sustainability manager. Insight into CE and SCM.	SCM, CE

B.1.2 Feedback

Table B-2 outlines the feedback that was provided by the experts as well as my response to the feedback received.

Table B-2 Content validity expert feedback

	Feedback

Expert 1	• For the e-mail/introduction letter, he suggested that:
	  ○ Need to check how it will work with being able to retract participation, how is this actually going to work, need to clearly communicate that with participants.
	  ○ When referring to the survey length, I should use: should take about.
	
	Items:
	• Regarding design: Sometimes you mix up the means and the end. Designing for modularity is a means, whereas durability or maintainability is an end. For design I should focus on a few end goals: durability, maintainability, upgradability, recyclability.
	• Would add sub-categories to design for durability, provide some more detail on the sub-practices that are involved in the different products.
	• Design of products for recycling; design for products for reusing components, refurbish, remanufacture of components in a different item. One is focused on life-extension of the product, the other on life-extension of the components.
	• The RO PSS categories are unclear. Unlikely that practitioners will understand what pay-per-result etc. is. I should try to reformulate them to make it more clear or change it / provide an example.

	Feedback
Expert 2	Overall: • Be more clear in terms of your header. Mention that you are investigating the link between servitization and circular supply chain practices. At the moment, simply saying circular economy is too vague. • The section in which I say that the participants do not get a direct benefit is underselling myself. I also contradict myself because I mention later on that they receive the results of the study. I should take it out. Items: • The instructions are too dense and repeat too much information from the e-mail. I should see how I can reduce the text. Just take out the things that were said before. • I should take out the part regarding that the work experience should suffice. Instead replace it with something along the lines of wanting to get different perspectives from companies. • I need to adjust the numbering. It's off at the moment. • Replace implementation with commissioning of products in PO PSS • Add short-term/long-term to help distinguish sharing and leasing in UO PSS • In narrowing (sustainable manufacturing), I should take out lean manufacturing as an example. First of all, the item is clear as it stands, secondly it can be argued that lean manufacturing has nothing to do with material/energy consumption. • In narrowing (supplier collaboration), take out the example of environmentally audited suppliers. That is not necessarily a product of collaboration.
Expert 3	Overall: • Be more explicit about what companies get: get insight into results, benchmark current performance against others in your industry. Regarding the survey: • Items / scale for survey is clear. Especially for PO PSS. For UO / RO PSS, it takes a long time to figure out what I mean. Need to provide better explanations for the services. • Explanation of what slowing, closing, narrowing means should be included in the survey so that the respondents don't get overwhelmed. • The threshold between 2 and 3 in the scale is unclear. What does planning to consider actually mean? Either you consider it or you don't. Maybe take out one of the two? • Need to maybe look at adaptability & upgradability. Are they different, if yes different items? • Do they understand help close resource loops? • Should change upstream with suppliers / downstream with customers to make it more clear. • I seem to be missing an item around increasing the recycled content in new products.

	Feedback
Expert 4	Regarding the survey: • Should shorten the question to a more active and direct form. Need to watch out and make sure that there is a consistent use of singular and plural when referring to products. He suggests to use the plural form to allow a broader understanding • Need to check outsourcing again in the literature. Do I mean that labour is provided for a process that the customer still controls or is the whole process outside the customer control. • Should add adjectives that describe the purpose. For example design for easier maintenance and repair. • In regards to ("design products for recycling"), it would help to clarify the difference between recyclability of the product or the practices that increase the recycling rate. Again, this is a difference between a product-level practice and a business model practice. Designing products for recyclability is more product-level and increasing recycling rates is more on a business model level. • In regards to the formulation, he suggests to maybe go from using nouns to more action terms (verbs) to describe the practices, which may be more engaging to the reader.
Expert 5	• Explanations for use- and result-oriented PSS are too verbose, combine too many aspects at once without using and/or • Is pay-per-use not more like a use-oriented? I know Tukker (2004) says something else, but especially if you think of car sharing, where is the difference? I think this makes more sense in use-oriented PSS. • Also, maybe use a different term for pay-per-result, such as performance-based contract or so… it may be more clear for practitioners… Practitioners do not typically use the academic terms we have. • Should also think about using examples to make it clear what I mean by the services. • Should add that activities relate to CE in question 4. • I think the items represent the ideas of slowing, closing, and narrowing in the circular economy well. • I am not sure whether some terms might need some more explanation or clarity for participants from industry, e.g., the sustainability manager will understand 'closing the loop activities' but will other respondents? • I think in the 'slowing' part you could have something like: Collection of used products from customers for reuse and resell, I feel this is different to reselling/ reusing returned products as it is active rather than reactive, alternatively maybe slightly reword "reuse or resale of products". • "design to reduce product impact" seems to be even broader/more open than the global item –maybe add 'during the use phase' as I think you are referring to the consumption side here • "design of production processes" I would add a verb, e.g. Redesign/Alter/Improve production processes…. • Should add some adjectives in the first CE category (e.g. ease of maintenance and repairs)

	Feedback
Expert 6	• PSS questions: To what extent is hard to understand. Scale doesn't really fit. I should think about reformulating the scale. It would be more: Not at all, somewhat, hardly…Instead, I could just go for 'very low', 'low'… • She suggested to stick with the extent: To a very small extent; small extent; moderate; great extent; very great extent. • Are rental sharing the same? Maybe take sharing out. • Perception: to make it the same, I should maybe add 'do you perceive' to all questions on CE and services • Explanation: Have an explanation of the different terms in the text itself, not in a glossary. • Same for the item on design for adaptability and upgradability. What exactly does this mean and could you maybe provide a practical example.

B.1.3 Synthesis of feedback

The feedback from the expert interviews provided a number of important avenues to improve the survey instrument. The main points from the experts as well as the changes that were implemented as a result are synthesised and explained in Table B-3.

Table B-3 Synthesis of expert feedback

Synthesised Feedback	Description	Change implemented
PSS Scale	Not balanced, wording does not align.	• Used a 0 for not at all; Used very low and very high as natural end-points of the scale.
Clarity of PSS items/terminology	Use- and result-oriented items / descriptions are verbose and confusing.	• Reduced wording for descriptions • Provided examples (especially for result-oriented) • Added more practitioner-friendly terminology (e.g. performance-based contract). • Provided example (pay for holes in walls instead of nails…) • Changed pay-per-use to use-oriented to prevent confusion with sharing…
Design strategies mix up means and ends	Design strategies mix up design means and ends.	• Reformulated design strategies so that they are all 'ends'. • This is still in line with previous classification (Bocken et al., 2016).

Comprehension/ terminology of SCC items	Concerns were raised around the understandability of the items.	• Reworded slowing, closing, narrowing categories • Slight wording adjustments/ refinements in individual items • Add definitions, examples to online survey

Firstly, it was mentioned by several respondents that the original scale was not well formulated. As mentioned in the survey development paper, this question intends to answer the service orientation of the manufacturer's business strategy (Homburg, Hoyer and Fassnacht, 2003). There are three aspects to this: the number of services, the broadness of services, and the emphasis on services. After a review of different operationalisations of this, the scale developed by Sousa and da Silveira (2017, 2019) was chosen, because it provided the most all-encompassing formulation in one scale. Nevertheless, the question's wording (to what extent) did not correspond well to the scale options (low/high). After careful deliberation with Academic 6, the decision was made to change the scale options (very small extent/very great extent). This increases the question and scale alignment for the two questions. In addition, it was mentioned by multiple experts that the items around use- and result-oriented PSS were unclear/ difficult to understand. Here, the biggest issue that was the descriptions were too verbose and sometimes not very clear. These types of contracts are difficult to grasp and I need to find a way to make it easy for practitioners. Some changes were adding more practitioner-friendly terminology, using examples to make the items clearer.

For the circular supply chain practices, there was also a misalignment between some of the design strategies. According Expert 1, the items were formulated in a way that mixed up the means and ends of the design strategy. This was chiefly the case with design for modularity, which was a strategy to achieve different desired ends, such as repairability. As a result, the design strategies for the slowing of resource loops were slightly adapted to focus on specific ends. The new design strategies are: durability, maintenance and repair, adaptability and upgradability, as well as refurbishment or remanufacturing. These updated design strategies are still in line with the goals that are outlined in the original classification (Bocken et al., 2016).

Finally, the point was raised that there was overall comprehension issues for the circular supply chain items. As a result, we changed some of the wordings, added descriptions to the online survey tool.

B.2 Pilot Study

This section outlines the results of the pilot test that was conducted for the English version of the survey. The pilot test helps ensure that potential errors are avoided and that the survey is designed well. The procedure for the pilot study was based on Thomas (2011). Participants were sent the survey and asked whether they could fill it in and answer the questions. The respondents had the choice of either having the survey administered in person in a 'think-aloud' interview or through written respondent debriefings (Thomas, 2011). The questions were based on the guidelines provided by Thomas (2011) and are as follows:

1. Will the cover letter/invitation motivate a response to the survey?
2. Are there any ambiguous or confusing questions?
3. Are there any concepts that you may not understand or unfamiliar terms?
4. Are the response choices (the scales)?
5. How long did it take you to fill in the survey?

B.2.1 Participants

The survey was piloted with eight industry experts who are currently employed in the UK or closely working with subsidiaries here. The results are summarised in Table B-4.

Table B-4 Pilot study experts

Expert	Role	Background	Feedback
Manager 1	Eco-Economics Specialist *Metals processing equipment manufacturer (NL/UK)*	Sustainability professional with 2 years of experience working for a metal processing equipment manufacturer. Mainly based in the Netherlands, but has running projects and work	Interview (ca. 30 min)

Expert	Role	Background	Feedback
		experience in the UK.	
Manager 2	Project Manager *Material Handling Equipment Manufacturer (UK/Sweden)*	Project manager with a material handling manufacturer in Sweden/UK. 7 years of work experience. Formally based in Sweden, but is also responsible for sales-related projects in the UK	Written
Manager 3	Project Manager *Processing equipment manufacturer (UK)*	Project manager with more than 12 years of work experience for mechanical engineering firms in UK.	Written
Manager 4	Head of Supply Chain *Plastic Packaging Machinery Equipment Manufacturer (UK)*	Head of Supply Chain for plastic packaging machinery manufacturer SME (UK).	Interview (ca. 30 min)
Manager 5	Sustainability Manager *Material Handling Equipment Manufacturer (UK)*	Sustainability manager with over 15+ years of industry experience.	Interview (ca. 30 min)
Manager 6	Head of Global Key Account Management *Precision Instrument Manufacturer (UK/SUI)*	Head of global key account management with 20+ years of experience for precision instrument manufacturer.	Interview (ca. 30 min)
Manager 7	Logistics Manager *Power tool manufacturer (UK)*	Logistics manager with over three years of experience in working with	Interview (ca. 30 min)
Manager 8	Product manager services *Power tool manufacturer (UK)*	Product manager for Hilti's fleet management services with three	Interview (ca. 20 min)

Expert	Role	Background	Feedback
		years of experience working.	

B.2.2 Pilot study feedback

Table B-5 summarises the feedback that was received in the pilot tests.

Table B-5 Pilot study feedback

	Feedback
Manager 1	• You could use something more clear, than “to what extent” in the answers. For example you ask “to what extent you provide spare parts and consumables?” I think you will get quite subjective answers here, which will not help you. You either do it or you don’t. • Same here. Perhaps in the leasing of the products, you could ask “what percentage of your business is leasing?”, and have an answer in percentage. It could be intrusive, but this is an anonymous survey, right”? • The scale “”not considering, planning, implementing”. it’s very easy to answer that! • Time for survey: 15 minutes
Manager 2	• I found the instructions very clear. • I found the questions and options very clear and could not find anything to improve. • In my opinion the goal of the survey is clear, questions are clear and it does not take too long to answer to them. Therefore I believe that people are able to find the time and are willing to complete the survey. • Time for survey: 10-15 minutes
Manager 3	• Thinks that the outsourcing service in 3.4 is a bit unclear. Wouldn’t it be in-sourcing? • Thinks that the scale for circular supply chain practices is unclear. Suggests instead that it should be how often these activities are carried out at the moment. • Otherwise thinks that it is clearly formulated. • Email could be a bit shorter to make it faster to read and understand. • Also mentioned that for an online survey it should be much easier than the word file. Should instead be in an online tool (which I will of course do). • Time for survey: 15 minutes

	Feedback
Manager 4	• In the letter, make it maybe more personalised why I contacted them. • Thinks that questions 2-3 are quite easy to be understood. Thinks that some of the offerings may not apply to all industries. • Thinks that the circular supply chain practices are quite clear. • Stumbled over supplier and customer collaboration and had to think of examples in practice. • Thinks that it should take around 10-15 minutes to answer.
Manager 5	• Thinks that the survey is generally quite clearly formulated. • Would go for a much shorter email version to practitioners. Maybe highlight the benefit more. Tease out that this is an important European research effort to increase the competitiveness of industry, meet sustainability targets. • Also had troubles with really identifying the difference between leasing, renting/sharing at the beginning. • Otherwise, thinks that some practitioners may have trouble knowing the answers, because the knowledge for this survey will be dispersed around many different departments. It will be relatively easy for people working in sustainability functions, but that will be hard to come by for the survey. • Suggested moving the questions on demographics to the front of the survey to ease up participants before they answer the more difficult ones. • Time for survey: 10 minutes
Manager 6	• Performance based contract, depends on what you consider for performance, how you measure it. Also at first thought of warranties. • Found that it was otherwise easy to understand, did not struggle particularly with any formulations. • Thinks that a potential problem may be answering for different business units, especially in a large company. • Thinks that some of the practices/services may not be suitable to all industries. May confuse some respondents. • Time for survey: 10 minutes
Manager 7	• Didn’t know what the pay-per-service unit was item meant. • Also had trouble understanding the performance-based contract. • Was insecure filling in the part on supply chain circularity, because she didn’t feel like she knew enough about it. • Time for survey 12 minutes
Manager 8	• Should bring demographics to the front to make it easier. • The services in use- and result-oriented take a long time to read. • The scale difference is a bit confusing. • Really need to think about the items for SCC practices, what they mean. Maybe I should make them more easily understood (for example glossary). • Thinks that it takes about 15 minutes to complete the survey.

B.2.3 Synthesis of feedback

The purpose of this section is to synthesise and outline the main takeaways from the pilot test and to outline the changes that were implemented. The synthesised feedback is discussed by the order of occurrence in the survey. The feedback and the changes implemented in the survey are depicted in Table B-6.

Table B-6 Synthesis of pilot study feedback and changes made

Survey section	Synthesised feedback	Description	Change implemented
Letter	Make a much shorter e-mail version to elicit responses	Write separate e-mail to	• Wrote a much shorter version of introduction for e-mail that focuses on benefits and importance of this research study.
	Make introduction more engaging	Pilot testers thought that the introduction letter could be improved	• Added purpose overall contribution of this research; added benefits to participants; broke content down with bullet points.
Structure	Move demographic questions to front	Feedback to move demographic questions to the front to ease respondents into the survey.	• Moved demographic questions to the front.
	Add sections	Add sections to increase the clarity	• Added four different sections and relevant descriptions to the survey outline.
Service offerings	Make service descriptions clearer (Q3)	Confusion regarding result-oriented PSS	• Updated the descriptions for pay-per-use, outsourcing, performance-based contract.
Circular supply chain practices	Clarify wording in some of the items	Some clarification needed for specific items	• Added adjectives to some items. • Changed the wording of product installation. • Clarified training in product use practice.
Timing	10-15 minutes	Administered surveys took participants 10-15 minutes, including explanations.	• Mention that survey takes about 10 minutes (this is considering time taken in the pilot).

The introduction letter was the first thing that was reviewed by the pilot testers. They mentioned the importance of shortening the letter, highlighting the benefit to companies and to society as a whole more, and providing clearer bullet points. Throughout this piloting phase, the letter was iteratively improved with the purpose of making it more engaging to the recipient and increasing the response rate. Instead, it was suggested to draft a shorter and bullet-point based e-mail to the practitioners.

There were also some comments made on the structure of the survey. The first suggestion was to switch the order of the questions and to introduce the demographics at the beginning. This was based on the rationale that it would help ease the participants into the survey. In addition, doing this allows for the demographics and company background questions to screen out possible respondents who are not in the desired population.

The second problem identified in these questions were the formulation for the use- and result-oriented PSS offerings. While administering the pilot surveys, it became clear that some of the respondents struggled with understanding these offerings. In the pay-per-use example, the new wording not only emphasised that the customer buys pays for using the product according to the level of use, but also that the service provider gives access (Gebauer, Haldimann and Saul, 2017).

In the case of outsourcing, some thought that it was difficult to understand. The main point raised by all of them was whether it referred to the manufacturer outsourcing activities to someone else or providing this service. As a result, the wording was changed from ‘taking over the operating risk and full responsibility for customer’s operating processes’ to ‘service provider manages one or more non-core activities for the customer’ (Gaiardelli et al., 2014; Gebauer, Paiola and Saccani, 2013). This change helps to address the comments, by clarifying that the service provider manages it for the customer. In the case of the performance-based contract, the main confusion stemmed from the addition of performance outcomes, such as product availability and reliability. After reviewing this type of offering in the literature, the wording was refined. Instead of focusing on just the

product outcomes, the new version stresses that the service provider is paid for delivering results, not for the provision of individual products or service (Kleemann and Essig, 2013; Ng, Ding and Yip, 2013; Visnjic et al., 2017). To make this more clear, an example was taken from the literature, namely that this type of service would deliver holes-in-walls and not power drills and repair services (Levitt, 1960). This clarification reduces the ambiguity of this item, because it specifies clearly that the provider is remunerated for delivering specific outcomes and not for the inputs required to achieve these.

Another comment was regarding some of the terminology used in circular supply chain practice items. Some of the respondents had trouble with understanding upgradability/ adaptability as well as remanufacturing/ refurbishment. As a result, the decision was made to include a glossary of terms, through a hover over function in Qualtrics to provide an explanation of potentially confusing terms. Finally, the majority of survey respondents took about 10-15 minutes to answer the survey.

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Appendix C – Case study method

This appendix provides some further details for the method used for the case study paper in Chapter 3.

C.1 Research strategy

Case study research is a powerful tool in operations and supply chain management research (Voss, Tsikriktsis and Frohlich, 2002). This methodology was chosen to study the phenomenon of supply chain circularity in PSSs, because it is well suited to answer the 'how' question underlying this research (Yin, 2018). Most importantly, however, it provides an in-depth and detailed understanding of context as well as the specific contingencies under which mechanisms occur (Gibbert, Ruigrok and Wicki, 2008; Tsoukas, 1989).

The research strategy in this paper emphasises a theory testing approach (Ketokivi and Choi, 2014). This case study approach makes it possible to contribute to theory development by falsifying existing theoretical assumptions about the contribution of PSSs on supply chain circularity (Tsang, 2014). The identification of cases that disconfirm theory make it possible to refine theory (Tsang, 2014).The contribution of PSSs on supply chain circularity is used to test the contextualised logic of the NRBV. The research was guided by *a priori* theoretical considerations and hypotheses that were deduced from the literature. The case study meets the duality criterion (Ketokivi and Choi, 2014) by being on one hand situationally grounded in the context of PSSs and on the other hand being embedded in the NRBV. Nevertheless, while a theory testing approach is driven by theoretical deduction, it is not exclusively limited to it (Ketokivi and Choi, 2014). The analysis of contextual factors that enable and inhibit supply chain circularity in PSSs, while guided by *a priori* considerations, remained open to unanticipated findings.

C.2 Case study selection

An important determinant for the external validity and the generalisability of case study research is the case selection (Yin, 2018). While quantitative surveys draw on samples taken from a population (Yin, 2018), case studies are not statistically

sampled and therefore do not rely on the same statistical generalisation. Instead, case studies rely on analytic generalisation, where the researcher draws generalisable conclusions from the research results (Yin, 2018). Cases are selected based on a replication logic instead of a sampling logic (Yin, 2018). That means that different cases can be used to independently corroborate different hypotheses (Eisenhardt, 1989). There are two forms of replication logic: literal or theoretical replication. In literal replication, the cases are used to predict similar results, whereas theoretical replication predicts different results but for predictable reasons (Yin, 2018). In this study, the selection of cases was based on literal replication logic since the hypotheses were predicted to be true in all cases. According to Yin (2018), a few cases (2-3) could be used for literal replication. Moreover, a multiple-case study is also better suited for theory testing case studies (Bitektine, 2008).

As described in Chapter 4, the phenomenon under study are the supply chain circularity contributions of PSSs. These PSSs are closely related to the servitization of manufacturing firms. Servitization is the organisational change process of firms moving from selling products to offering PSSs (Baines et al., 2017). The servitization phenomenon has primarily been described in the Western context, particularly in Europe (Luoto, Brax and Kohtamäki, 2017). In addition, the servitization literature focuses also primarily on machinery and equipment manufacturing firms (Baines and Shi, 2015; Luoto, Brax and Kohtamäki, 2017; Martinez et al., 2010).

The selection of the manufacturing firms were as follows:

- Organisation in machinery or equipment manufacturing sector:
- Based in Europe, ideally in the UK to facilitate data collection;
- Should offer at least two different types of PSSs (see Table C-1 for an overview).

Based on firm names or industries mentioned in the literature, a search, selection, and engagement process was started. A list of companies was formed and prioritised and these companies were approached through informal networks to key personnel. One difficulty was classifying a firm’s offering within the PSS

framework (Gaiardelli et al., 2014). Many offerings were not clearly described on firm websites, for example, in regard to product ownership or risk transfer, making an identification of result-oriented PSSs particularly difficult.

To increase the generalisability of findings and prevent any competitive concerns between competing firms, it was important to ensure industry diversity among the sampled firms. Diversity was sought according to the speed of product innovation cycles in an industry (industry clockspeed). This concept of industry clockspeed describes the speed of change within an industry as well as the length of existing product lifecycles (Fernández and Kekäle, 2006; Fine, 1998). The choice was motivated by the fact that economic, technical, functional or aesthetic obsolescence was previously identified as a barrier to supply chain circularity in PSSs (Linder and Williander, 2017; Zeeuw van der Laan and Aurisicchio, 2020).

In terms of identifying the units of analysis, care was taken to make sure that the PSSs were representative of the potential PSSs identified in the literature. The selection criteria of the units of analysis were as follows:

- Should be adhere or fit to existing classification of PSSs types (see Table C-1) (Gaiardelli et al., 2014);
- There should be at least two categories (i.e. product-oriented, use-oriented, result-oriented PSS) implemented to ease comparison within and across companies and to allow for a better isolation of the various contextual factors;
- Should be implemented for the same product to facilitate comparison;
- Should be already implemented.

Table C-1 Excerpt of potential PSSs (Gaiardelli et al., 2014)

Unit of Analysis	Types of offerings	Description	Case example
Product-oriented PSS	Product installation	The PSS provider sets-up or installs the equipment in exchange for a fee.	HP installs hardware, software for customers' IT operations.
	Repair and maintenance	The PSS provider offers repair and maintenance services for products either on- or off-site.	Philips Healthcare provides a global remote diagnostic service to facilitate repair.
	Remanufacturing/ refurbishing	The PSS provider sells remanufactured/refurbished products for the existing products.	The Caterpillar Certified Rebuild Program sells remanufactured products.
	Extended warranty	PSS provider an product warranty period in exchange for a fee.	PC, Consumer electronics
	Recycling and take-back	PSS provider removes equipment and gives it to recycling companies.	Common for electronics, home appliances.
	Help desk (for product)	PSS Provider gives assistance on how to use, maintain and repair the product through phone or email.	Vaillant provides a help desk to assist with maintenance problems for customers.
Use-oriented PSS	Leasing	Lessee pays a regular fee in exchange for unlimited and individual use of the product.	Leasing contracts for cars (e.g. Volvo).
	Renting	Customer uses product individually for a predetermined period.	Car rental (e.g. Europcar)
Result-oriented PSS	Pay-per-result	Customer pays for a pre-determined result. Provider covers activities needed for outcome delivery.	Orica provides a functionality-based pay-per-result mining solution (Rock On the Ground).
	Outsourcing	Provider takes responsibility for engineering, planning, executing, and managing all maintenance activities for an entire plant.	ABB takes over the responsibility for engineering, planning, managing maintenance activities for an entire plant.

C.3 Data collection

The case studies were started sequentially, but carried out simultaneously. The overall data collection lasted from July 2019 to March 2020. Both primary and secondary data was collected for each case. The research design encouraged both source and method triangulation to help ensure the quality and rigour of the case study findings. In addition, a mix of qualitative (i.e. words) and quantitative (i.e. numbers) evidence was sought to help further triangulate the findings and increase their reliability (Eisenhardt, 1989; Yin, 2018).

C.3.1 Interviews

Data was initially collected through interviews. For each case, a main contact person was established to help with approaching the right contacts. The interviewees were selected based on their knowledge of the PSSs as well as their implementation in regard to supply chain circularity. The interviews were taped to ensure that no information was missed, transcribed and the interviewees asked to check the transcript afterwards.

The interviews were conducted in a semi-structured manner. In this type of interview, informants are asked a series of pre-determined but open-ended questions (Given, 2008). As suggested, an interview guide was derived from the conceptual map (see Appendix D). The questions were based around the PSS characteristics, supply chain circularity outcomes as well as the internal and external context. The selection of interview questions was based on the expertise of the informant as well as on how well the interview was flowing and whether the main points were being addressed by the interviewee.

A total of 21 interviews were carried out with 19 individuals, lasting about 40 minutes on average. Having multiple respondents helped to improve data reliability and validity (Yin, 2018). An overview of the anonymised respondents is provided in Table C-2. The vast majority of interviews were conducted face-to-face, with especially the final interviews being held via telephone due to COVID-19 restrictions.

As can be seen in Table C-2, the interviews conducted in the Toolco and Windco case significantly outnumbered the ones for the Computerco case. This is due to the fact that the interviewees were highly knowledgeable of the studied phenomenon with one interviewee being responsible for increasing the sustainability of its business services and the other interviewee being Computerco's global lead for CE implementation. In addition, since Computerco is a frontrunner in CE implementation, there was a large amount of secondary information available, such as company reports and even a lifecycle assessment, which provided in-depth information regarding the implementation of the PSSs as well as information on the slowing and closing of resource loops.

Table C-2 Overview of interviewees

Case	Interviewee Role	Code	Duration	Type
Toolco	Marketing Director	Int1	56:16	F
	Account Manager	Int2	27:02	F
	Product Manager	Int3	62:13	F
	Marketing Director	Int4	51:07	F
	Marketing Manager	Int5	60:27	F
	Sustainability Director	Int6	58:34	P
	Head of Repair Services	Int8	59:20	F
	Account Manager	Int18	45:20	P
Computerco	Manager Sustainability Services & Stewardship	Int7	49:20	F
	Senior Director for Global Sustainable Impact Operations (Global CE Lead)	Int9	47:18	P
Windco	Product Lifecycle Management Director	Int10	57:48	F
	Service Manager	Int11	42:30	F
	Research & Development Manager	Int12	45:29	F
	Operations Manager	Int13	35:38	F
	Operations Manager	Int14	44:35	F
	Sustainability Manager (Group Interview)	Int15	1:28:22	F
	Sustainability Manager (Group Interview)	Int16	1:28:22	F
	Business Development Manager	Int17	30:42	P
	Head of Overhaul & Repair	Int19	47:13	P

Note: F = face-to-face; P = telephone

C.3.2 Documents & secondary data

Triangulation of evidence will also be sought by collecting different sources of documentary evidence. These are explained in more detail in Table C-3. The gathered documentary evidence ranged from company reports and press briefings to service contracts as well internal presentations, product design information or lifecycle assessments. This data is expected to be both quantitative and qualitative in nature. These data sources will also be used to corroborate any interview data.

Since the organisations included in this research were all large multinational companies, there was a significant amount of secondary data available, either through the company's intranet or publicly available. Across all three cases, there was a lot of information available that provided additional insight and perspective on the implementation of the PSSs, the supply chain circularity implications as well as the internal and external context of the companies. This was especially the case for Computerco. Due to its longstanding engagement with CE, there were many presentations, lifecycle assessments, company strategies, case reports, sustainability reports and other documents available that provided helpful qualitative and quantitative information on the circularity of their PSSs.

Table C-3 Overview of documentary evidence

Case	Aspect	Documentary Evidence	Total # of documents
Computerco	PSSs characteristics	Marketing presentations & brochures, press briefings, company reports	23
	Slowing & closing	Company presentations & reports, lifecycle assessment results (use-oriented PSS vs. product-oriented PSS), environmental product declarations, sustainability reports and figures	
	Context	Marketing presentations, product & service brochures, press briefings, company reports	
Toolco	PSSs characteristics	Marketing presentations & brochures, press briefings, company reports	17
	Slowing & closing	Company presentations & reports, internal circularity assessments, database information, sustainability reports and figures	

Case	Aspect	Documentary Evidence	Total # of documents
	Context	Marketing presentations, product & service brochures, press briefings	
Windco	PSSs characteristics	Marketing presentations & brochures, press briefings, company reports	33
	Slowing & closing	Company presentations, database information, sustainability reports and figures	
	Context	Marketing presentations & brochures, press briefings, company reports	

C.3.3 Observations

The final source of evidence came from observations. Unfortunately, Toolco was the only case company that offered the opportunity for an observation. This was combined with an interview with the manager of the repair service centre. Due to internal company guidelines, I was not allowed to take pictures during the visit.

Table C-4 Overview of observations

Case	Observation Activity	Time	Date
Toolco	Tour of the service and repair centre in Glasgow. Observation included watching the repair activities, site for decommissioned tools as well as the inbound and outbound logistics for tools sent for repair.	2 hrs	17/10/2019

C.4 Data analysis

This section describes and explains the methods chosen for the data analysis.

All data sources were uploaded into Nvivo 11 for analysis. Each unit of analysis was assigned as a distinct case in Nvivo. For each case company, the first step was to write a detailed within case-study report (10 pages), which consolidated the information from the analysis of all primary and secondary data sources.

Within case analysis

For the within-case data analysis, template analysis and pattern matching were used as an analytical technique (Yin, 2018). Template analysis is a variant of thematic analysis of qualitative data that uses a flexible tentative *a priori* coding

structure which helps to guide the researcher in finding relevant information from the text. Template analysis allows the initial codes to evolve as codes may emerge, be inserted, deleted or merged. This method was chosen because it fits with research that seeks to understand the generative mechanisms between variables (King, 2012). Based on the theoretical framework *a priori* coding structure was developed with initial first-order codes. The coding structure will be used henceforth as a template, when analysing the data again and iteratively amended until a final template emerges. In addition, pattern matching was employed (Yin, 2018). This method involves comparing a theoretical pattern with an observed empirical one. A pattern is a non-random arrangement of objects or entities that can be described (Trochim, 1989). Pattern matching involves an attempt to link a theoretical and an empirical pattern (Trochim, 1989).

For deductive case studies, pattern matching involves a series of steps (Hyde, 2000; Yin, 2018):

1. Stating theoretical hypotheses before the data-gathering commences: This was operationalised through the stating of hypotheses in the paper, based on the logic of the NRBV.
2. Providing an alternative explanation or counter-theory: Alternative explanations were initially developed through the definition of enablers and barriers that affect supply chain circularity outcomes in PSSs.
3. Gather and compare case data to see if pattern matches predicted outcome or alternative explanation: Based on the collected data, the original hypotheses were compared with the contextual factors to identify the most suitable explanation for supply chain circularity outcomes across the units of analysis.

This analytical technique was employed for the within-case analysis as well as for the cross-case analysis.

Table C-5 Initial coding structure

Category	Sub-Category	Aspect
PSS Business Model	Value Proposition	Objectives / value proposition of the offering
	Orientation of the offering	Product User
		Product Owner
		Product Decision-Maker
	Focus of the offering	Intensity of the relationship
		Customisation of the offering
	Focus of the Offering	Pricing Mechanism
		Risk Management
Slowing & Closing	Initial Lifetime	Design of products for durability
		Initial lifetime of products
		Maintenance/repair of products
		Design of products for ease of maintenance and repair
		Design of products for upgradability
	Refurbishment Contribution	Return of products
		Refurbishment or remanufacturing
		Reuse or resale of products
	Recycling Contribution	Design of products for recycling
		Use of recycled materials in product
		Recycling
	Slowing Outcome	Product longevity
	Closing Outcome	Closure of resource loops
Internal Context (Enablers & Barriers)	Organisational	
	Financial	
	Technology & Knowledge	
External Context (Enablers & Barriers)	Market	
	Supply Chain	
	Regulatory	

Cross-case analysis

The cross-case analysis will use the tactic of finding differences and similarities between the cases (Eisenhardt, 1989). For this, *pattern matching* will be used in a similar fashion as in the within-case analysis.

C.5 Documentation of case study evidence

This section provides an overview of the evidence underlying the analysis in Chapter 4.

C.5.1 Evidence for application of PSSs

This section provides an overview of the evidence from the three case studies that informed Table 4-3 in Section 4.4.1 (see Table C-6).

Table C-6 Evidence for PSS characteristics across the units of analysis

Content	**Sample Evidence**	**Type of Evidence**
Computerco Case		
Product Owner		
Product-oriented: "Customer"	"Absolutely – he may want to refresh his new PC and then he has to get rid of his old one – we will actually consult him and say Computerco is offering all these services - you can have either a recycling depending on the age of your PC, it can be recycled by Computerco directly or we can refurbish it and we will get further value out of it – it's similar to a car, so depending on the age of your car you will resell it or dispose of it…." - Computerco, Sustainability & Services Manager (Int7)	Interview
	"Ownership and authority: Confirm you are at least 18 years of age and that you have the right to sell your device. Additionally, confirm that you are a commercial customer or that you represent a commercial customer and have the power and authority to enter into this agreement." - Computerco, Marketing Brochure	Document

Content	Sample Evidence	Type of Evidence
Use-oriented: "Manufacturer"	"If the unit is owned outright by the customer, the end-of-life is the customer's choice – if it is leased and owned by us, it will be picked up at the end of the lease period and we will take care of it." - Computerco, Sustainability & Services Manager (Int7)	Interview
	"Product as a Service replaces ownership-based models with usage-based services. COMPUTERCO is moving into the product as a service business model by focusing on leasing, renting and other service contracts PC services." -Computerco, Company Report	Document
Product User & Decision-Maker		
Product-oriented: "Customer"	"If the unit is owned outright by the customer, the end-of-life is the customer's choice – if it is leased and owned by us, it will be picked up at the end of the lease period and we will take care of it." - Computerco, Sustainability & Services Manager (Int7)	Interview
Use-oriented: "Customer"	"It's part of our sales and refresh training – if we refresh the products then you also know that we will take it back." - Computerco, Sustainability & Services Manager (Int7)	Interview
	"Choose a device mix that's as unique as your business, with a wide selection of Computerco commercial notebooks, desktops, and mobile and specialised products, including Computerco Chrome Enterprise devices." - Computerco, Marketing Brochure	Document
Customisation		
Product-oriented: *Low* – Pretty standard. Equipment pick-up can be specified.	"Some customers tell us 'right, we have your employees but we need to have someone to pick up the unit and brings it into a special room before it is being picked up for the renewal; Other customers say	Interview

Content	Sample Evidence	Type of Evidence
	'ok we can do it ourselves." - Computerco, Sustainability & Services Manager (Int7)	
Use-oriented: *High* – Three different service levels with additional scope options.	"Services are completely customised, especially if we talk about the customers – the customers all have different needs and some customers want people on-site and by this I mean Computerco people onsite to manage their PC fleet as a person who can respond to questions but other customers may want a helpdesk, they want to have it online, they want to have it offline or onsite." - Computerco, Sustainability & Services Manager (Int7)	Interview
	"Computerco DaaS has three plans to choose from: Standard, Enhanced or Premium. Whether you manage in-house or take advantage of the Computerco -managed service with our specialised service experts using leading, cloud-based unified endpoint management tools on your behalf, we'll help you deliver more proactive security, support, and management for multi-OS device environments." - Computerco, Marketing Brochure	Document
Relationship Intensity		
Product-oriented: *Low* – Single transaction without recurring relationship.	"When it's time to retire old PCs and devices, you want to be sure the job gets done the right way. With support for the circular economy, let Computerco take charge of your retired equipment in a secure, efficient, and environmentally sound manner." - Computerco, Marketing Brochure	Document
Use-oriented: *High*– Ongoing service relationship; Option for co-located staff.	"The customers all have different needs and some customers want people on-site and by this I mean Computerco people onsite to manage their PC fleet as a person who can respond to questions but other customers may want an online helpdesk." - Computerco, Sustainability & Services Manager (Int7)	Interview

Content	Sample Evidence	Type of Evidence
Risk Transfer		
Product-oriented: "*Customer* – No risk transfer"	"What we offer is compliance assurance and risk management including data cleansing (as you have your data security issue)." - Computerco, Circular Economy Director (Int9) Note: Outside the scope of SCC	Interview
Use-oriented: "*Manufacturer* - Computerco assumes repair, damage, IT & security risks."	"We have predictive software on our PCs which tells us when there is risk and then we coordinate the repair or we suggest what should happen when at which moment…." - Computerco, Sustainability & Services Manager (Int7)	Interview
	"Transform endpoints from your biggest risk to your best defense Complement your Computerco DaaS plan and protect against zero-day threats and human errors with Computerco Proactive Security. The service provides real-time malware protection for computing endpoints, security and threat analytics, and specialised expertise to help you strengthen your security position." - Computerco, Marketing Brochure	Document
Payment Mechanism		
Product-oriented: *Mark-up* - Depends on equipment and service scope.	"Computerco Device Recovery Service: Computerco delivers a simple yet complete solution that includes the secure and sustainable repurposing of your end-of-use devices and provides you with the residual value. Fair market value will be assessed based on age and condition of the device. Not all devices may have any residual value. If not, they will be responsibly recycled." - Computerco, Marketing Brochure	Document
Use-oriented: *Fixed fee* - Fixed monthly leasing fee depends on scope of offering.	"Don't pay for more than you use. Tailor your solution with Computerco Lifecycle Services— from design to configuration, maintenance, and end of use—and financial terms to meet your needs with the	Document

Content	Sample Evidence	Type of Evidence
	convenience of a single price per device. Flex your devices and services up or down based on changing workplace or workforce needs." - Computerco, Marketing Brochure	
	"You pay a subscription – like Netflix or Spotify." - Computerco, Circular Economy Director (Int9)	Interview
Toolco Case		
Product Owner		
Product-oriented: "Customer"	"…we also have the [product-oriented] contract which just means the customer owns the tool and has a little bit longer coverage…" – Toolco, Marketing Director (Int1)	Interview
	"The other way you can buy Toolco is to basically to do an outright purchase and then it comes with a warranty." (Mark)	Interview
Use-oriented: "Manufacturer"	"When you buy a tool, you can either have it on Fleet contract and Fleet is basically (Toolco) owned, so customer rented or you can own the tool outright." – Toolco, Marketing Director (Int1)	Interview
	"Contractual Products remain the property of [Toolco]." – Contract (Document)	Document
Product User & Decision-Maker		
Product-oriented: "Customer"	"The customer goes out and buy their fleet tools, the account manager delivers them and shows them how to use the tool." - Toolco, Product Manager (Int3)	Interview
	Our customer service teams can: • Give you advice about our Toolco products, software or services. • Find stock availability and place an order for you. • Help you find the best delivery solution	Document

Content	Sample Evidence	Type of Evidence
	• Arrange a service or repair for your Toolco tools. - Toolco, Company Website	
Use-oriented: "Customer"	"When you get your fleet delivered, you get full training for your customers but also you get some documentation on, e.g., how do you actually send it in for repair; how do you call customer services." - Toolco, Product Manager (Int3)	Interview
	Supports product sales • Advice on best products to use • Training on product use in applications • Service consulting: making best choice of quick fix, full repair, or trade-in - Toolco, Company Presentation	Document
Customisation		
Product-oriented: "*Low* - Standardised offering that comes with all purchased tools."	"There are no customisation options" - Toolco, Product Manager (Int3)	Interview
Use-oriented: "*Low* – Standardised offering. Contract length only customisation option."	"In GB it is quite strict. Sometimes we can negotiate the usage times per customer but they are usually subject to approvals from certain people in the sales hire or sales director and so on if we go below certain limits or longer limits because we need to see whether it is still viable." – Toolco, Marketing Director (Int1)	Interview
	"We do offer specific customisation – they can get a reduced fleet term that would obviously increase the monthly price slightly but it would offer the customer the flexibility in terms of choosing how long they really need the tools for." - Toolco, Product Manager (Int3)	Interview
Relationship Intensity		

Content	Sample Evidence	Type of Evidence
Product-oriented: "*High* – Regular visits to customer sites, regardless of business model."	Does Toolco have the same intensity of relationship with an outright purchase customer versus a fleet customer? "I would certainly say so yes…" – Toolco, Marketing Director (Int1) "It depends very much on the account management because we are very much account manager centric so it depends how well the account manager knows the customer and how often they visit the customer; it depends on the size of the customer and so on – it could be the account manager visits the customer every month or it might be they visit them every 3 months – it depends whether the customer has any problems and calls the account manager" – Toolco, Marketing Director (Int1)	Interview
Use-oriented: "*High* – Regular visits to customer sites, regardless of business model."	"Our account managers try to visit customers once a week or at least once a month, depending on the size of the customer. (…) The customer buying our tools outright may only have a small portion of these tools and so you really have to keep that customer engaged and buying so they almost require more intense observation and management than a fleet [use-oriented PSS] customer." - Toolco, Product Manager (Int3)	Interview
Risk Transfer		
Product-oriented: *Customer* - repairs for free for two years, repair costs are capped after year two.	Making a promise to repair all tools within 3 days or free 2. We give 2 years of free repairs – including wear and tear, pick-up and delivery 3. A capped repair cost after the 2 year period 4. Lifetime warranty for manufacturing/material faults 5. A new 3 month free repair period after each subsequent paid repair	Document

Content	Sample Evidence	Type of Evidence
	- Toolco, Internal Presentation; Website	
	"[Toolco] will always repair [bought] tools throughout their entire life and we have a repair cost cap which is between 30% and 40% of the tool price when it is new so you will never be paying excessive fees for repair and obviously as a result of that our customers choose to repair or renew these tools as often as possible until the tool is as dead as a dodo and then that is the end…" - Toolco, Product Manager (Int3)	Interview
Use-oriented: *Manufacturer* - free repairs, theft & damage protection to loan tools.	"6 Services for 1 monthly payment: • Financing: Just pay for use of the tools – no money up front, predictable future costs • Tool Inventory and Labelling: Personalised tools for total online transparency and easy invoice consolidation • Loan Tools: Tools on loan minimise downtime in the event of repairs • Theft Coverage: Reduces risks and makes replacement of tools easy in case of theft and loss • Tool Exchange: Keeps you equipped with up-to-date tools for top productivity in the interest of health and safety • No Cost Repairs: Fast, quality repairs, free of charge for the entire period of use. Also including dropped tools." - Toolco, Internal Presentation, Website	Document
Payment Mechanism		
Product-oriented: "*Mark-up* – Fixed price for tools."	"It is a financial lease [use-oriented] – so we get monthly payments as opposed to getting the full payment up front [product-oriented]…" - Toolco, Product Manager (Int3)	Interview
	"When you buy a [Toolco] tool, you get more than just a tool. You also get the super fast Toolco tool repair service." – Toolco, Internal Presentation	Document

Content	Sample Evidence	Type of Evidence
Use-oriented: "*Fixed fee* - Fixed monthly leasing fee depends on scope of offering."	"The customer's single monthly payment („Total Monthly Usage Fee") shall be calculated by combining the Monthly Usage Fee for all individual Contractual Products (consisting of usage and applicable service fees) as set forth in the Tool List." – Toolco, Fleet Contract	Document
	"It is a financial lease [use-oriented] – so we get monthly payments as opposed to getting the full payment up front [product-oriented]…" - Toolco, Product Manager (Int3)	Interview
Windco		
Product Owner		
Product-oriented "Customer"	"The customer is the owner and operator of the wind turbine for both the annual service and the availability contract. We are an OEM, not a bank. From a finance perspective, it would not make too much sense. We would have to keep the wind turbines on our books, which is not desirable." - Windco, Operations Manager (Int13)	Interview
	"There are some cases in which we own the turbine up to the point of operation, and then we sell it off. So we do not own the turbines." - Windco, Service Manager (Int11)	Interview
Result-oriented PSS *"Customer* –Windco does not retain turbine ownership (turbine project finance)."	"The customer is the owner and operator of the wind turbine for both the annual service and the availability contract. We are an OEM, not a bank. From a finance perspective, it would not make too much sense. We would have to keep the wind turbines on our books, which is not desirable." - Windco, Operations Manager (Int13)	Interview
	"There are some cases in which we own the turbine up to the point of operation, and then we sell it off. So we	Interview

Content	Sample Evidence	Type of Evidence
	do not own the turbines." - Windco, Service Manager (Int11)	
Product User		
Product-oriented "Customer"	"The customer is the owner and operator of the wind turbine for both the annual service and the availability contract." - Windco, Operations Manager (Int13)	Interview
Result-oriented "Customer"	"The operator is the customer and we are the maintenance service provider for the customer." - Windco, Operations Manager (Int14)	Interview
Product Decision-maker		
Product-oriented "Customer"	"In regard to maintenance, customers have to organise it themselves." - Windco, Operations Manager (Int13)	Interview
	"This is for customers who already have the capabilities of doing maintenance and repair." - Windco, Service Manager (Int11)	Interview
Result-oriented *Manufacturer* -Windco plans and carries out service operations.	"We control the turbine for maintenance purposes." - Windco, Service Manager (Int11)	Interview
	The operator is the customer and we are the maintenance service provider for the customer. - Windco, Operations Manager (Int14)	Interview
Customisation		
Product-oriented: *Low* – Standard inspection checklist.	"We have a standard checklist of things we do, such as checking hydraulics or putting in new filters, but that's it." - Windco, Service Manager (Int11)	Interview
	"We have a standard checklist, where we have to check certain things. For example, in the first year it could be that we have to tighten every fifth bolt. In the fifth year we have to tighten all the bolts again. Then,	Interview

Content	Sample Evidence	Type of Evidence
	in ten years, we have to change the oil." - Windco, Operations Manager (Int14)	
Result-oriented *High* – Completely customised to meet customer requirements.	"Selected additional service products: Unscheduled service, service tools, basic training, technical support, condition monitoring reporting, wind farm operations, component warranties, mods & ups, spare parts, extended service scope." - Windco, Marketing Brochure	Document
	"We have included maintenance, troubleshooting, cranes, lift inspections and remote monitoring. So everything we offer. You can optionally buy extra things again, which also depends on the national context. It always depends on what the customer wants." - Windco, Operations Manager (Int13)	Interview
Relationship Intensity		
Product-oriented PSS *Low* – Annual service, otherwise no interaction.	"We visit the site once or twice per year to conduct preventive service (e.g. change the filters, the oils etc.) – the basic things. Once something is breaking, we go to the customer and ask if he wants to fix it and then we make offer a quote for the repairs." - Windco, Service Manager (Int11)	Interview
	"Communication is the other way around, compared to the availability contract. We conduct our annual service and if a turbine breaks down, we would call and make an offer. Do you have interest? Either yes or no." - Windco, Operations Manager (Int13)	Interview
Result-oriented PSS *High* – Co-located staff, regular exchange (e.g. phone calls with customer)	"Our contact with customers is at least weekly and we have contractual monthly reports that we share. We often share daily reports with them as well and the customer often provides us with feedback if they are not happy with the daily production." - Windco, Operations Manager (Int14)	Interview

Content	Sample Evidence	Type of Evidence
	"We work very closely with the operator and try to be as close as much as possible. If you have any errors, the operator will of course be informed and contact us or vice versa. We are working very closely together there." - Windco, Operations Manager (Int13)	Interview
	"Customer communication: Submit monthly report (monthly availability figures, major outages, planned service works for the following month); Report verbally to customer in case of any accident; In case of a major defect provide customer with a technical defects report; Communication and response to customer requests; Inform customer of any observed damage/irregularities." - Windco, Marketing Brochure	Document
Risk Transfer		
Product-oriented *Customer* - Customer bears operational risks.	"The basic contract has very limited risks for us." - Windco, Service Manager (Int11)	Interview
	"With the full scope contract and the availability that we guarantee, the risk shifts from customer to us." - Windco, Operations Manager (Int13)	Interview
Result-oriented *Manufacturer* - Windco takes on turbine availability risks.	For the performance-based contracts, the risk is large because we take the complete risk of downtime of turbines. If five blades break within one year, then the risk on the availability is on us." - Windco, Service Manager (Int11)	Interview
	"We sell percentage availability. No matter whether the wind is blowing or not. And of course the risk we take is that we guarantee the turbine is running." - Windco, Operations Manager (Int14)	Interview
	"As all the key parameters are known – wind, turbine availability, O&M costs and price of energy – Life	Interview

Content	Sample Evidence	Type of Evidence
	Extension represents a minor risk investment for Windco's customers." - Windco, Marketing Brochure	
Payment Mechanism		
Product-oriented PSS *Fixed fee* - Annual service is based on a fixed fee.	"If you only choose the standard service, you pay a fixed annual price per turbine." - Windco, Operations Manager (Int14)	Interview
	"Fixed fee - so the most basic one is the fixed fee for the annual service for the period they wish to have it." - Windco, Service Manager (Int11)	Interview
Result-oriented PSS *Performance-based*– Payments based on turbine availability	"Performance based contracts – so then we get into the performance based contracts where we would say availability – there, what we prefer to offer is a fixed basic fee but then, based on the performance, have upsides and penalties – so penalties if it gets below the promised availability and upsides if it is above the promised availability, which gives us an incentive to ensure uptime beyond the promised minimum…" - Windco, Service Manager (Int11)	Interview
	"High availability warranty is standard. It includes a 95% Availability Warranty averaged over the contract term with a 3 month allowance of 90% for the running in period in the first year. Incentive sharing mechanism for warranted availability over 96%; 25% Windco share for additional availability (96% - 97%); 50% Windco share for additional availability (above 97%)." - Windco, Marketing Brochure	Document

C.5.2 Evidence for slowing and closing across the PSSs

This section provides an overview of the evidence from the three case studies that informed Table 4-4 in Section 4.4.2 (see Table C-7).

Table C-7 Evidence for comparison of slowing and closing across the cases

Content	Sample Evidence	Type of Evidence
Computerco Case		
Initial Lifetime		
Product-oriented: "2-4 years"	Initial lifetime (years): 2-4 years – Computerco, Internal LCA Study	Document
2-4 years. Spare parts available for 5 years after end of production.	Availability of spare parts after end of production: 5 years – Product Information Statement	Document
Use-oriented: "Contracts typically range from 3-5 years."	"Most of the contracts are like 3 year contracts – there might be 5 year contracts…." - Computerco, Sustainability & Services Manager (Int7)	Interview
	"Yes – there are different product lifecycles in the PC industry depending on the type of product because for instance, enterprise solutions typically require longer lifecycles and they may want to have the same model for a longer time…." - Computerco, Sustainability & Services Manager (Int7)	Interview
	"As a hospital, for example, you need to be much more strict and you don't want to update your software very often – so you want everything to be stable and perform well – and each time you change your operating system, you have to make sure all your applications are still running on your new operating system, so stability is a big factor…." - Computerco, Sustainability & Services Manager (Int7)	Interview
Refurbishment contribution:		

Content	Sample Evidence	Type of Evidence
Product-oriented & Use-oriented: " ~80% of all returned products are refurbished. Refurbished lifetime expected to be between 1-3 years."	Lifetime 1 (years): 2-4 years Lifetime 2 (years): 1-3 years Reuse Rate (after Rerfurbishment): ~80% – Computerco, Internal LCA Study	Document
Use-oriented	"With focus on materials sustainability, the DaaS business model aims to maximise materials efficiency and reuse through product life time extension and reuse opportunities." – Computerco, Internal LCA Study	Document
	"When the customer buys a 3-5 year service we are not going to throw that piece of kit in the trash or recycle it or refurbish it and use it." - Computerco, Circular Economy Director (Int9)	Interview
Recycling contribution:		
Product-oriented: "In product-oriented PSS, return rate not clear. Currently around 50% for computers in the UK."	"The refurbished computers get resold and reused – there is a market – I don't have details on the market but we know they are not going into landfill – so we try to control that as best as possible…" - Computerco, Sustainability & Services Manager (Int7)	Interview
	"If you go to one of your local authority tips or recycling centres, you will see there is not a lot of IT there. Typically, it is not getting as far as your municipal waste scheme because somebody has already taken care of it - and so I think it is a misconception that just because we don't have figures, that it all must be going to waste because it isn't – it will be somewhere and so yes of course there is an element of things getting thrown in the trash by mistake but I think, particularly for corporate and commercial equipment, even the small companies will be looking to sell those	Interview

Content	Sample Evidence	Type of Evidence
	devices." - Computerco, Circular Economy Director (Int9)	
Use-oriented: "About 75% of use-oriented notebooks returned and ~20% of those are recycled (~95% recyclability)."	"There will always be some leakage but I think it will be pretty close to 100% - you wouldn't expect it to be 30% or 40% but you would expect it to be 75% and upwards…" - Computerco, Circular Economy Director (Int9)	Interview
	This product contains 0% post-consumer recycled plastic (by wt.) - Computerco, Technical Product Specifications	Document
	This product is 95.1% recycleable when properly disposed of at end of life. - Computerco, Technical Product Specifications	Document
	"We published a goal this year that by 2025 we would have 30% of recycled content across our entire product range – and at the moment we are around about 13-14% across the product range – some products have over 80% of recycled content as I said and some products have none." - Computerco, Circular Economy Director (Int9)	Interview
	"What we offer is compliance assurance and risk management including data cleansing (as you have your data security issue) but also I think a lot of companies are beginning to realise there are significant environment and social responsibility and risk around making sure things are recycled properly." - Computerco, Circular Economy Director (Int9)	Interview
Toolco Case		
Initial Lifetime		
Product-oriented: "2-4 years. Free repairs for the first two years,	"We have had tools that have come into the repair centre that were 20/25 years old, fully functional and have been used on a daily basis but not very heavily,	Interview

Content	Sample Evidence	Type of Evidence
then capped at 30-40% of new tool price. Depending on use intensity, the lifetime can reach up to 15-20 years."	so it really depends on how heavily you use the tool and what application you use them for than the general tool lifetime. But in general I would say that with [Toolco] tools, they have roughly got the expected lifetime of the FM contract." - Toolco, Product Manager (Int3)	
Use-oriented: Same products as in product-oriented PSS. About 30% of customers extend contract by 3-5 months.	"…the contract can be anything from typically 24 months to 48 months." - Toolco, Product Manager (Int3)	Interview
	"Fleet Management is a lease contract based on monthly payments for a fixed term of 24,36,48 months etc." - Toolco, Internal Presentation	Document
Refurbishment contribution:		
Product-oriented: No refurbishment and reuse of used tools.	"So far, no customers that own Toolco tools have returned used tools for reuse or recycling." – Notes from observation in Service & Repair Centre.	Observation Notes
Use-oriented: About 85% of tools are returned.	Collection rate of 85.9% for 2019 sent as an Excel sheet.	Document
	"…the collection rate is up to 80% if not more…" - Toolco, Product Manager (Int3)	Interview
	"it's hard to put a percentage on it but at a very rough guess, I would say 60% of those tools are reusable." - Toolco, Head of Repair Services (Int8)	Interview
Use-oriented: About ~1-3% in good enough condition to be reused as loan tools.	"First, to my knowledge, it will come back to the Glasgow repair centre and then a very small number, which is I believe between 1-3% will be retained to be FM loan tools." – Toolco, Marketing Director (Int4)	Interview
	"Reuse of loan tools accounts for only a very small % of overall returned fleet tools." – Toolco, Internal Presentation	Document

Content	Sample Evidence	Type of Evidence
	“There is a one digit percentage of tools that can be reused in the as loan tools, after they return.” - Toolco, Sustainability Director (Int6)	Interview
Refurbishment of rotor and electronics	“The Fleet tools are destroyed so we looked at what parts can we reuse from those Fleet tools and put them into normal repair - and basically now we are limited to just two types of parts; one of which is electronics – so electronics can be interchangeable between the same type of tool; and the second one is the rotor...” - Toolco, Head of Repair Services (Int8)	Interview
	Calculation of spare parts refurbishment accounting for 10% of new tool value based on excerpt of Excel data.	Document
Recycling contribution:		
Product-oriented: “Recycling rate of power tools in the UK around 21%. Customers typically have large unused stock of old tools.”	21% collection rate based on EUROSTAT average of last three 2016-2019.	Document
	“When I go out to visit customers, they have pallets of old tools lying around. They say that someday they will send it back to us or recycle them.” - Toolco, Account Manager (Int18)	Interview
	“From what we see when we go onsite they normally have a big bin or pallet somewhere with old and broken tools which once every blue moon gets collected and scrapped. It is highly unlikely that they go through the cost of reselling it because it take so much time and resource to make the tool presentable.” - Toolco, Product Manager (Int3)	Interview
Use-oriented: “Around ~85% of tools recovered after end of contract. Of these	“Collection rate of 85.9% for 2019.” -Toolco, Excerpt of Excel data	Document
	Recycling rate of returned fleet tools listed in an internal document (91.3%)	Document

Content	Sample Evidence	Type of Evidence
around ~91% are recycled.”	“…the collection rate is up to 80% if not more…” - Toolco, Product Manager (Int3)	Interview
	“~95% given as an average recyclability for Toolco tools.” – Toolco, Internal Presentation	Document
	“most of the power-tools specifically would have a recyclability percentage between 95% and 97% actually when you think of, is it possible for these raw materials if disassembled to be recycled, then the answer would be over 95% yes…” – Toolco, Marketing Director (Int4)	Interview
	“In Europe we are having one company that organises the recycling for us and also working together with some of the state of the art recycling plants with very, very high material recycling rates.” – Toolco, Sustainability Director (Int6)	Interview
Windco Case		
Initial Lifetime:		
Product-oriented & Result-oriented: “20-25 years standard lifetime.”	“So when we design our turbines, we design in accordance with specific standards and we apply the IEC 61400 standards and this standard say the minimum lifetime is 20 years and then we have seen as a market request, the need to extend this lifetime and so try to design our towers to last 25 years up front and we do this first for offshore but now also for onshore – so something between 20-25 years is our planned certified design lifetime.” – Windco, Product Lifecycle Management Director (Int10)	Interview
	“It typically ranges from 20 to 25 years – but can in some cases even increase to 30 years, depending on the conditions and the wind turbine itself.” – Winco, Research & Development Manager (Int12)	Interview

Content	Sample Evidence	Type of Evidence
Result-oriented “Extension by up to 10 years possible. Windco can minimise costs compared to product-oriented PSS, but lifetime extension depends customer preferences.”	The main, most immediate benefits for the customers are: • 10 additional years of income that will be maintained in the long-term through an availability guarantee. • More reliable turbines that are easier to maintain, keeping O&M costs low. Besides these obvious advantages, Windco proposes: • A long term & full service O&M contract to guarantee that operational costs are stabilised at the level generally incurred on a 10-year-old wind farm. • A tailored investment & financing plan, based on technical audits of individual turbines, with the aim of achieving optimised cash flow for Windco’s customers. - Windco, Marketing Brochure	Document
	“Windco has the operational experience and technical expertise to provide the high-level technological solutions needed by its customers.” - Windco, Marketing Brochure	Document
	“The best way to extend the lifetime is to limit the loads on the turbine. This decision, ultimately depends on the preferred cash flow of the customer. It is a balance of both short term revenue as well as extending lifetimes. Customers want to minimise the levelised cost of energy. If you can have a very long lifetime, your cost per KW hour is rather low.” - Windco, Service Manager (Int11)	Interview
	“The cutting-edge life extension solutions represent a minor risk investment considering that Windco has the necessary operational experience and technical expertise, and has already performed turbine upgrades. This proven capability will back up our customers’ decision to modify their accounting rules,	Document

Content	Sample Evidence	Type of Evidence
	making them more profitable in an uncertain global economy.” - Windco, Marketing Brochure	
	“The useful life extension program involves investing in preventive and corrective activities -only when it is really necessary- to keep wind turbines working for 30 years, so an immediate replacement of the existing components is not required.” - Windco, Marketing Brochure	Document
Product-oriented & Result-oriented: “Potential for turbine reuse abroad.”	“There are smaller companies that are very active in decommissioning and which are rebuilding old plants in developing countries.” - Windco, Business Development Manager (Int17)	Interview
Refurbishment contribution:		
Product-oriented & Result-oriented: No difference between the units of analysis. Component refurbishment available for several large and small components. Available to both PSS types. Same expected lifetime and performance as new components, for 80% of the cost.	“We have a pool of working refurbished components, which we deliver to the site and install in the turbine. We then take these old and broken components, refurbish them "as-new" and keep them in our pool for future installation.” - Windco, Business Development Manager (Int17)	Interview
	“The average moving price is also different; in most regions it is around 80% of the new price.” – Windco, Head of Overhaul and Repair (Int19)	Interview
	“The reconditioning of major components performed by Windco involves extending the useful life of blades, gearboxes, and generators, mainly by enhancing their constituent parts or by replacing these elements with the latest technological advances. In some cases, as a preventive measure, or during repairs, the damaged parts are replaced with the same original element.” - Windco, Marketing Brochure	Document
Recycling contribution:		

Content	Sample Evidence	Type of Evidence
Product-oriented & Result-oriented: No difference between the units of analysis. Not yet relevant, since vast majority of turbines are still in use. Customers required to recycle turbines at end-of-life. Expected to be high, since customers required by law to decommission and recycle.	About 80-90% of the mass of a wind turbine can be recycled (Bundesverband Windenergie, 2019).	Document
	“There are very few turbines that have already been decommissioned. Typically, this is done by smaller companies who try to sell the components for recycling. What is not so And that which cannot be sold is scrapped. The biggest problem at the moment is with the blades, which are partly built with glass fibres, so recycling is difficult.” - Windco, Business Development Manager (Int17)	Interview
	“The owner is also legally forced to build reserves for decommissioning. This is a percentage of the value of the asset that is built up over the period of reserves so that the capital is available at the end of its life to decommission the asset.” - Windco, Business Development Manager (Int17)	Interview
	“We do have recycled content in our turbines. It depends on where you are and what the market gives you. We only specify the strength of the steel and this can be with recycled or non-recycled material.” - Windco, Sustainability Manager (Int15)	Interview

C.5.3 Evidence for the role of contextual factors

This section provides an overview of the evidence from the three case studies that informed Table 4-6 and Table 4-7 in Section 4.4.3 (see Table C-8).

Table C-8 Evidence for enabling and inhibiting effect of internal contextual factors

Content	Sample Evidence	Type of Evidence
Computerco Case		

Content	Sample Evidence	Type of Evidence
Pro-environmental culture **Enabler - Slowing & Closing:** Encourages employees to identify innovation opportunities to slow and close resource loops, for example by improving maintenance.	"Sustainability is a core value of the company – definitely. I can give you an example – there was the recent march for the climate and a message came from our CEO to all employees saying 'feel free to go' – so he was saying this is really a priority for Computerco and he wanted to encourage all the employees to take part in that…." - Computerco, Sustainability & Services Manager (Int7)	Interview
	"Our commitment to CE is a natural evolution from our 25-year-old recycling programmes. From the beginning, our founders had the principle of 'Global Citizenship' - behaving well towards the society that we are in is one of our core values." - Computerco, Circular Economy Director (Int9)	Interview
	"The circular economy framework appeals to Computerco because it provides a comprehensive, unified approach to environmental footprint reduction. It brings many of Computerco's environmental priorities together under one umbrella, including resource and energy efficiency (its design for the environment program) and the use of more benign materials, providing guidance on what to prioritise." - Computerco, Company Report	Document
Integration of CE in company strategy and goals **Enabler - Slowing & Closing:** Encourages employees to identify innovation opportunities to slow and close resource loops, for example by	"In the strategy of each business unit, there is one pillar called circular economy. So increasing circular economy is part of their key goals." - Computerco, Sustainability & Services Manager (Int7)	Interview
	"Being a responsible company is part of our DNA – and people are measured on that - and if you hear that all the time, you adhere to it. … There is a lot of thought around doing things better, such as cutting down onsite repairs, doing preventive maintenance before the unit is broken to help consolidate the	Interview

Content	Sample Evidence	Type of Evidence
improving maintenance.	customer visits." - Computerco, Sustainability & Services Manager (Int7)	
	"Applying a circular economy lens to its business opens up opportunities for disruptive innovation at Computerco. By developing and applying advanced information technologies, Computerco can help scale the growth of the circular economy and create a competitive advantage." - Computerco, Company Report	Document

	Our priorities:
	• Decoupling growth from consumption:
	  ○ Dematerialisation and increased recycled content
	  ○ Durability and repairability
	  ○ Product repair, reuse, and recycling
	• Transforming industry business models:
	  ○ Shift from transactional to service-based business models
	  ○ Digitising supply chains to reduce waste and cost
	• Collaborating with partners and customers:
	  ○ Building new circular supply chains
	  ○ Supporting customers
	- Computerco, Company Report
		Document

<u>New factor:</u> Serving different customer segments **Enabler - Slowing**: Provides cascade opportunities to re-market refurbished equipment to different market segments,	"We do not want the returned products to go on the open market but want to bring them back into our own economic cycle. You will soon see products moving through multiple cascades: from large commercial and public sector customers through to consumers." - Computerco, Circular Economy Director (Int9)	Interview
	"I think you might start off with a very high end PC with a graphic designer and then it might come from there and go into like a school or hospital or small company where it might be used for fairly basic stuff and then go	Interview

Content	Sample Evidence	Type of Evidence
without risk of product cannibalisation.	to someone like my mother who is really only doing emails on it and a bit of internet searching – she is not trying to plan a high end games – she is not trying to do a heavy mass of number crunching on massive spreadsheets – so it is a very different type of use – so you have a cascade of different users." - Computerco, Circular Economy Director (Int9)	
The ability to design products for circularity **Enabler - Slowing & Closing**: Facilitates effective and efficient CE practices, such as repair, refurbishment, recycling.	"A key Computerco material conservation priority is modular product design to support repairability and aid eventual refurbishment and upgrading to extend the life of its product lines. It is increasingly focused on designing products to be easily serviced and is ramping up the incorporation of smart technology to enable prompt servicing and repair." - Computerco, Company Report	Document
	"There is a big effort to increase the reparability of our products – this is an integral part of the strategy of Computerco. There are Electronic Product Environmental Assessment Tool (EPEAT) requirements and certifications. Among our competitors, we have by far the number one position." - Computerco, Sustainability & Services Manager (Int7)	Interview
Toolco Case		
Integration of CE in company strategy and goals: **Barrier – Slowing**: Hesitance in the past of management to drive CE/sustainability agenda internally.	"Last year we had the first top down environmental strategy. But that has been recognised by the company so that is why we now have the clear direction to further develop the sustainability strategy." - Toolco, Sustainability Director (Int6)	Interview
	"When we extended the 2020 corporate strategy to 2023, we added environmental sustainability as one of the main topics to look deeper into and how we will structure this sustainability and integrate it into our	Interview

Content	Sample Evidence	Type of Evidence
	core services, such as Fleet and hopefully improve…"- Toolco, Account Manager (Int18)	
	"Up to now there has been a bit of reluctance within the company in regard to refurbishment just because we are a premium brand and there wasn't the appetite to create a secondary brand or cannibalise the market for ourselves…" -Toolco, Sustainability Director (Int6)	Interview
Premium brand positioning / Differentiation strategy: **Enabler - Slowing & Closing:** Brand image focused on the quality and dependability of products and services. Ensures durability, repairability, recyclability of products as well as quality repair services.	"Our value proposition as a premium brand is to meet our customers' strategic concerns, such as productivity, health and safety, tool durability." – Toolco, Marketing Director (Int4)	Interview
	"The second core competency is the superior quality of our products. Although the price of our products is a bit higher compared to our competition, one of the reasons is the quality and the durability of the products…" – Toolco, Account Manager (Int2)	Interview
	"I think that it mainly comes down to the good quality products and services that we provide to our customers that differentiates us from our competitors." – Toolco, Marketing Manager (Int5)	Interview
Premium brand positioning / Differentiation strategy: **Barrier – Slowing**: Refurbishment of products and perceived lower product quality regarded as	"By us openly offering a cheaper, inferior product, it could fundamentally undermine what we as a premium brand stand for." - Toolco, Marketing Director (Int4)	Interview
	"Up to now there has been a bit of reluctance within the company in regard to refurbishment just because we are a premium brand and there wasn't the appetite to create a secondary brand or cannibalise the market for ourselves…" -Toolco, Sustainability Director (Int6)	Interview

Content	Sample Evidence	Type of Evidence
undermining premium brand image.		
<u>New factor:</u> Serving different customer segments **Barrier – Slowing:** Toolco only serves business customers. Increased risks of product sales cannibalisation, since no other segments are served.	"Generally I don't think Toolco has been too interested in the B2C market so I don't know if something like that would work with some of our customers." – Toolco, Marketing Director (Int1)	Interview
Risk of product sales cannibalisation **Barrier - Slowing**: Company wants products returned from lease to ensure decommissioning, prevent cannibalisation of new product sales.	"You do not want to have these tools resurfacing, because we want to promote the value proposition of those new tools and encourage their sale." - Toolco, Head of Repair Services (Int8)	Interview
	"Because if the customer at the end of the contract keeps this tool, we then lose this customer, which loses engagement and means they just stop buying from us…" - Toolco, Product Manager (Int3)	Interview
Lack of a clear financial business case **Barrier - Slowing & Closing**: No clear business case / customer need around supply chain circularity	"Then you need to think, what actually is the business case and whilst I say sustainability is a big mega trend, there is not right now a super tangible business case." - Toolco, Marketing Director (Int4)	Interview
	"I think it mainly depends on the size of the customer. In the interactions with smaller customers, that is not something that they highly emphasise. However, I would say environmental strategies or visions about sustainability business, that only happens when you	Interview

Content	Sample Evidence	Type of Evidence
yet that Toolco can tap into.	are talking about the bigger customers where that is then stemming from them e.g., being on the stock market so you then have a pressure from the surrounding society to do something about it." - Toolco, Marketing Manager (Int5)	
Digital capabilities (collection of product information & data) **Barrier - Slowing**: Usage data available, but not considered into contract lengths. Results in usable products being decommissioned before the end of their technical lifetime.	"As our tools get smarter, those return cycles will be extended depending on the usage of the tool – One option is something like an hour counter, which would enable us to make sure that tools would come back to us at the end of their lifetime and not too much before." – Toolco, Sustainability Director (Int6)	Interview
	"I think in the some of the data enhanced tools that we have introduced with some of our tools so we can log e.g., how much has it been used and that kind of thing and we can then contribute into that to make sure the tools last even longer." - Toolco, Marketing Manager (Int5)	Interview
The ability to design products for circularity **Enabler - Slowing & Closing:** Facilitates effective and efficient CE practices, such as repair, refurbishment, recycling.	"When a tool is launched we obviously have the product managers who interface with the customers and there is always a repair representative on that design board for the tool and they are the voice of the repair team and try to bring in new creative ideas from a repair perspective to make it better for the whole customer experience." - Toolco, Head of Repair Services (Int8)	Interview
	"Global Tool Service is currently experimenting how to reuse parts of tools for another life in other tools / modules" – Toolco, Internal Presentation "Parts such as tool rotors for products such as SFC, DAG/DCG, TE40/50/60/70 can be repaired and refurbished for prolonged use" – Toolco, Internal Presentation	Document
Windco Case		

Content	Sample Evidence	Type of Evidence
Premium brand positioning / Differentiation strategy **Enabler - Slowing:** Focus on quality ensures product durability products and components.	"We were always a quality leader. Of course, we also had a few warranty cases, but compared to other companies, especially with regard to the blades, we perform well." – Windco, Product Lifecycle Management Director (Int10)	Interview
	"Our competitiveness in services is based on our quality as well as the know-how and expertise that we have developed over time." – Windco, Head of Overhaul and Repair (Int19)	Interview
	"We have always had high quality standards and we also try to keep up with the price. In addition, we have really good and experienced technicians in the field." - Windco, Operations Manager (Int13)	Interview
Lack of a clear financial business case **Barrier - Closing**: No clear business case for Windco to offer decommissioning and recycling services, due to low margins and volume.	"Turbine decommissioning is nothing that you can build a scalable process around. It is suitable for more agile companies and more spontaneous solutions and approaches than large companies like Windco. Also, the margin is not large enough." – Windco, Business Development Manager (Int17)	Interview
	"I believe we will use an eco system of sub contractors to do this – someone who specialiSes in this rather than trying to do this ourselves – our capabilities are in designing and procuring, selling and assembling." – Windco, Sustainability Manager (Int15)	Interview
Digital capabilities (collection of product information & data) **Enabler - Slowing**: Extensive use of remote monitoring and diagnostic technology	"Although Condition Monitoring is often seen as a plus for onshore turbines, Windco does use the continuous and critical data for Structural Health Monitoring System, anticipating risks in the structures. As the wind farm ages, and particularly during the proposed extended life period, this guarantees safe operating conditions, both for the structure and for the operator. This monitoring is all the more critical as preventive	Document

Content	Sample Evidence	Type of Evidence
helps prevent component damage, keep operation costs low, thereby extending product lifetime.	interventions and upgrades cost on average 80% less than corrective actions." - Windco, Marketing Brochure	
	"There are 452 sensors in a modern turbine, which monitor the health of the turbines and give an alert, if something is wrong. Around 90% of symptoms that it may have can be cleared remotely." – Windco, Sustainability Manager (Int15)	Interview
	"This monitoring is all the more critical as preventive interventions and upgrades cost on average 80 % less than corrective actions." - Windco, Marketing Brochure	Document
The ability to design products for circularity **Enabler - Slowing & Closing:** Facilitates effective and efficient CE practices, such as repair, refurbishment, recycling.	"Windco can transfer the latest design improvements to the existing fleet, making these machines more reliable and easier to maintain." -Windco, Marketing Brochure	Document
	"When we design a turbine, we include stakeholders – also from service – and ask them what they want and need. They have certain requests concerning e.g., automatic notification systems, remote diagnostic abilities and stuff like that – and of course we will try and incorporate all of that…" – Windco, Product Lifecycle Management Director (Int10)	Interview

Table C-9 Evidence for enabling and inhibiting effect of external contextual factors

Content	Sample Evidence	Type of Evidence
Computerco Case		

Content	Sample Evidence	Type of Evidence
Increased environmental awareness of customers **Enabler –Slowing & Closing**: Creates need for CE-related services, such as refurbishment or recycling.	"I think a lot of companies are beginning to realise the importance of recycling properly to manage significant environmental, social responsibility as well as IT data security risks." - Computerco, Circular Economy Director (Int9)	Interview
	"It is a growing market – this is primarily due to customer demand. There are different factors to consider here: the customers are really buying computing – for some of the customers, it is easier to understand that and to transform to this and for others, it takes a little longer. I think there is also a strong sustainability argument – so the big enterprise will have to take care of the renewal and refurbishment, which you as a customer don't need to take care of anymore - but it really goes together." - Computerco, Sustainability & Services Manager (Int7)	Interview
	"The circular economy concept helps companies address macro trends. It provides a signpost of what will be important to customers and businesses in the future. It positions Computerco to prepare for these trends." - Computerco, Company Report	Document
Lack of customer acceptance for circular products or business models **Barrier - Slowing & Closing**: Especially public sector customers struggle with changing procurement processes to lease products over buying them outright.	"It requires quite a mindset change to go from procuring a product to procuring a product-as-a-service. Particularly in the public sector, many budgets are annualised and so planning that needs for a four- or five-year lifecycle is much more difficult to do." - Computerco, Circular Economy Director (Int9)	Interview
	"A consumer mind-shift is needed to reward circular economy innovation. The millennial generation is more receptive to product as a service while older generations are less likely to share, lease or borrow. Equally, enterprise buyers usually favor lowest cost purchases over products with a lower total cost of ownership which considers the direct and indirect	Document

Content	Sample Evidence	Type of Evidence
	lifetime costs of product ownership." - Computerco, Company Report	
Lack of supply network support (e.g., suitable partners) **Barrier - Closing**: Lack of supply of high quality recycled materials, make it difficult to increase recycled content in products.	It is hard to find useable recycled plastic. We use very highly engineered plastic like ABS and HIPS and other types of hard engineering plastics. Plastic is completely different from metals recycling. If you mix different types of plastic together you get a plastic that is pretty useless for most things and we can't use it. So it has been all about the stimulation of that industry to understand what the secondary market wants from those plastics. The plastics have to behave correctly in our molds in the factories – so therefore we have to make sure we are procuring the right plastic. - Computerco, Circular Economy Director (Int9)	Interview
	"Not every plastic can be used and the plastic has to be stable. From a plastic perspective, we really want to make a difference, but we have to ensure that there is no negative impact on how robust the product is" - Computerco, Sustainability & Services Manager (Int7)	Interview
Ineffective waste/ recycling regulations **Barrier - Closing**: Difficulty of managing waste logistics in Europe due to regulatory restrictions on cross-border transports.	"Legislative barriers: Government policy and regulation have not kept pace with circular economy requirements. For example, in the EU all electronics are considered waste and difficult to move across borders. This makes it challenging to enable product take-back and consolidate repair." - Computerco, Company Report	Document
	"Other barriers are around logistics and cross border shipments, which due to regulatory pressures are quite difficult to do." - Computerco, Circular Economy Director (Int9)	Interview
Toolco Case		

Content	Sample Evidence	Type of Evidence
Speed of industry innovation cycles **Barrier - Slowing**: Innovations around cordless tools create need in the market for new tools, make it more attractive for customers to upgrade to new equipment.	"The rate of innovation is definitely increasing – particularly around cordless tools. I think every year we put more and more money into the research and innovation and hence there are always new tools and it is not only the tools coming out, it is also the consumables and accessories as well…" – Toolco, Marketing Director (Int1)	Interview
	"The product lifecycle has become shorter because we are introducing tools into the market faster than a couple of years ago and the customer needs are changing and we need to follow those needs. So for example, in the past, most of our tools were corded and recently we are introducing more cordless tools into the market – so there has been a shift in customers needs from corded to cordless products." – Toolco, Account Manager (Int2)	Interview
Lack of customer acceptance for circular products or business models **Barrier - Slowing**: Customers are poor in sending tools for repair. Will buy new products instead.	"Even though customers have the incentive to send tools for repairs, they are fairly poor in doing so. In the construction industry, there is a culture or image of not really caring." - Toolco, Account Manager (Int18)	Interview
	"It really depends totally on the trade and rate of trade in – usually the tilting point is when they send the tools for repair and they have the cost estimate on that one – they can then review whether it is better to renew or repair as that will include the average usage time and I would assume the lifetime is something similar to fleet management…" – Toolco, Marketing Director (Int1)	Interview
Lack of customer acceptance for circular products or business models **Barrier - Slowing**: Customers attribute	"Customers in Sweden are more aware of this durability and they're buying more into these value propositions of tool longevity compared to UK customers." – Toolco, Marketing Director (Int4)	Interview

Content	Sample Evidence	Type of Evidence
little value to product quality & durability in UK market.		
New factor: Vertical integration **Enabler - Slowing & Closing**: Incentivises Toolco to ensure the repairability and durability of tools as well as seek opportunities to capture value, such as component refurbishment.	"I think we are good because we are so integrated in our company when it comes to production in design and production and repair so I think that is a unique advantage and we are not using it enough and we have to elaborate on that a bit more because it is the great differentiator to other companies." -Toolco, Sustainability Director (Int6)	Interview
	"We are doing them ourselves so it is around 3 days in time but those could be the critical two or three days when the customer needs the loan tools so we can ensure that everything keeps going. Like the loan and repairs are faster usually compared to the rest of the services and we do it in-house rather than via third parties…" – Toolco, Marketing Director (Int1)	Interview
	"When a tool is launched we obviously have the product managers who interface with the customers and there is always a repair representative on that design board for the tool and they are the voice of the repair team and try to bring in new creative ideas from a repair perspective to make it better for the whole customer experience." - Toolco, Head of Repair Services (Int8)	Interview
New factor: Competitive issues with other supply chain partners **Barrier - Slowing**: Innovation towards result-oriented PSSs and potentially higher	"One option to make the current fleet management solution more circular is a model where you buy capacity – so having a number of tools of a specific type. This way, we could have more options to exchange tools– maybe even use refurbished ones. The main barrier for such a sharing model is that we could compete with some of our customers, who are	Interview

Content	Sample Evidence	Type of Evidence
levels of slowing prevented, since Toolco does not want to compete with its tool hire customers.	tool-hire companies." – Toolco, Product Manager (Int18)	
Supportive regulations, taxation, subsidies **Barrier - Slowing & Closing:** Lack of regulation to create need in the construction industry for circular products or business models.	At some point, it will have to be some form of regulation. We have seen in the past that regulation around silica dust and hand tool vibration really had an impact on the market. But we need that socio-political drive to push this and create the customer need that we can then tap into." – Toolco, Marketing Director (Int4)	Interview
	"The other part is the interest in creating regulation or legislation around this. The construction industry hasn't been that targeted in the past but the pressure on the construction industry to become sustainable and circular is growing…" – Toolco, Marketing Manager (Int5)	Interview
Windco Case		
<u>New factor:</u> Price sensitivity of customer **Enabler - Slowing**: Downward pressure on price enables Windco to compete through refurbishment services.	"Chief among these complexities is the relentless downward movement of price. Double-digit price declines have been observed in certain markets in just the last two years. Government-funded support schemes are in some cases declining or disappearing altogether, and energy owners and operators bid highly competitive rates to sustain or build their renewables portfolios. The effect is the downward pressure on both CAPEX and OPEX as owners seek paths to reduce cost and increase returns." - Windco, Marketing Brochure	Document
	"The subsidies keep going down. We have absolute cost pressure. The projects are sold for less and less, i.e. to the operators. And, of course, the operators	Interview

Content	Sample Evidence	Type of Evidence
	pass this on to us." - Windco, Operations Manager (Int13)	
	"There is big competition and I think right now we are trying to not just provide maintenance services, but to build up our service business strategically, for example through refurbishment. It is about getting the knowhow in-house, growing our portfolio and optimising the cost and quality of what we do." – Windco, Head of Overhaul and Repair (Int19)	Interview
Speed of industry innovation cycles **Barrier - Slowing**: Shortening product lifecycles make it more attractive for customers to upgrade to larger turbines. Limit lifetime extension opportunities.	"The lifecycles have become extremely squeezed due to high competition. Instead of 10-11 years (in total), we now only have 1-2 years to develop a new product and to run it for 3-4 years, before we phase it out again." – Windco, Product Lifecycle Management Director (Int10)	Interview
	"In the current price competition, the entire sales period of a generation of wind turbines until they are replaced on the market by the next generation of turbines has been drastically reduced. With this trend towards shorter product lifecycles, product development must also react accordingly and the total development period must be reduced." – Windco, Internal Report	Document
Lack of customer acceptance for circular products or business models **Barrier - Slowing**: High costs and low revenues can make	"As a customer, you have to ask yourself, does it make sense to leave an old turbine until it gives up or does it make sense to take it down now and repower it, so put a new and more powerful one in? That's always a question of official permits, payments and feed-in-tariffs. If you repower, you have the potential to make more money, but you also need to apply for a new permit, which is currently very difficult in Germany, and	Interview

Content	Sample Evidence	Type of Evidence
lifetime extension business case difficult for Windco customers	you will also lose the subsidies." - Windco, Operations Manager (Int13)	
	"It is to be expected that older turbines will only be able to achieve lower average prices in the market, since due to the lower hub heights and larger surface area, a large proportion of the old turbines will only generate and feed in electricity at higher wind speeds - when the exchange price falls due to the increased supply." - Quentin, Sudhaus and Endell (2018)	Document
	"The machines can either be operated in such a way that they achieve the longest possible service life, which results in increased maintenance effort and additional costs. Alternatively, operating costs can be reduced with low maintenance, but this increases the wear and tear on the machines and ultimately minimises their running time." - Quentin, Sudhaus and Endell (2018)	
<u>New factor:</u> Vertical integration **Enabler - Slowing**: Allows Windco to make hardware/software upgrades that make turbine more reliable or easier to maintain.	"As a completely vertically integrated manufacturer which maintains more than 70% of its turbines, Windco brings in-depth and extensive know-how. Thanks to this experience, Windco can transfer the latest design improvements to the existing fleet, making these machines more reliable and easier to maintain." - Windco, Marketing Brochure	Document
Supportive regulations, taxation, subsidies **Enabler - Closing**: Customers required by law to build capital	"The owner is also legally forced to build reserves for decommissioning. This is a percentage of the value of the asset that is built up over the period of reserves so that the capital is available at the end of its life to decommission the asset." - Windco, Business Development Manager (Int17)	Interview

Content	Sample Evidence	Type of Evidence
reserves for decommissioning and recycling.	“Germany is pushing the industry a decommissioning standard or guidance, but that is still under development there is no predicting when the turbines are to come down…” - Windco, Sustainability Manager (Int15)	Interview
Supportive regulations, taxation, subsidies **Barrier - Slowing**: Phase out of government subsidies make a customer’s business case for lifetime extension more difficult.	“When the entitlement to subsidies under the Renewable Energy Sources Act (EEG) for the first wind turbines expires at the end of 2020, the question will have to be answered as to whether the turbines can be continue to be operated (economically). Under the current conditions, the continued operation of the plants will only be economically viable for a very small proportion of the plants.” - Quentin, Sudhaus and Endell (2018)	Document
	“The subsidies keep going down. We have absolute cost pressure. The projects are sold for less and less, i.e. to the operators. And, of course, the operators pass this on to us.” - Windco, Operations Manager (Int13)	Interview

C.6 Rigour of case study research

According to Yin (2018), there are four common tests to establish the rigour of the research design. Throughout the study, various strategies and techniques were employed to meet the quality criteria of case study research (see Table C-10) (Yin, 2018).

Table C-10 Case study tactics for ensuring quality of research (Yin, 2018)

Quality Test	Description	Case study tactic
Construct validity	Identifies correct operational measures for the concepts being measured.	• Data triangulation: Mixing different sources of data (e.g. interviews, documentary evidence, observations) • Method triangulation: Different approaches to collecting data (i.e. interviews, document analysis & observations); qualitative & quantitative data sources.
Internal validity	Seeks to establish a causal relationship.	• Use of pattern matching and explanation building in data analysis to build causal chains and explain inference.
External validity	Defines the domain to which the study can be generalised.	• Literal replication logic and multiple case studies to test hypotheses. • Generalisability due to theory falsification
Reliability	Ensures that the operational aspects of study can be repeated.	• Development of case study database • Data management plan: I am following Cranfield University's data management process to ensure best practice.

C.6.1 Construct validity

To meet the test of construct validity, a research needs to do two things: 1) the phenomenon of interest in terms of specific concepts (and relate them to the research objectives) and 2) identify operational measures that match the concepts. As described in Chapter 3, specific constructs and operational measures were defined to guide and facilitate the date collection. The characteristics of the PSS types were based on an established classification system for PSSs (Gaiardelli et al., 2014). For the slowing and closing of resource loops, a set of established metrics was used that determines these outcomes based on the initial lifetime/use, refurbishment contribution as well as recycling contribution (Figge et al., 2018). This approach ensured that the case study methodology was operationalised with previously defined concepts from the literature that closely matched the concepts defined in the conceptual framework.

After defining the relevant constructs and operational measures, multiple sources of evidence were used to ensure construct validity (Yin, 2018).In social research,

using multiple sources of evidence is best achieved by using multiple methods and measures of an empirical phenomenon, also called triangulation (Mills, Durepos and Wiebe, 2010). There are four types of triangulation (Yin, 2018):

1) data triangulation;
2) investigator triangulation;
3) methodological triangulation;
4) theory triangulation.

This study employed data triangulation as well as methodological triangulation to ensure construct validity. In regard to data triangulation, this study relied on collecting data from different sources. As explained in the data collection section, data was collected through different interviewees as well as varying documents, such as presentations or reports to help provide a variety of different sources. For methodological triangulation, different approaches to data collection were conducted, namely interviews or document analysis. In addition, both qualitative (e.g. interviews) and quantitative (e.g. database evidence on return flows, lifecycle assessment data) evidence was used. Using quantitative and qualitative data together is considered highly synergistic, since it can help bolster and corroborate findings (Eisenhardt, 1989).

C.6.2 Internal validity

Establishing internal validity is a key concern for explanatory case studies like this one (Yin, 2018). It ensures the correct establishment of a causal relationship, in which one condition is believed to lead to another condition. Pattern matching is one of the best strategies for establishing internal validity (Yin, 2018).In this tactic, empirical patterns are compared to a predicted one (Trochim, 1989). In this study, outcome pattern matching was employed (Trochim, 1989). This technique focuses on matching a theoretical pattern of expected outcomes to an observed pattern of effects (Trochim, 1989).

According to the research framework, each unit of analysis was based around the PSS characteristics, the initial lifetime, refurbishment contribution, recycling contribution as well as the slowing and closing outcomes. The evidence and

measures relating to these constructs were compared across the units of analysis and the results compared with those predicted by the hypotheses (Trochim, 1989). The pattern matching process is described in more detail in Section A.4.

C.6.3 External validity

External validity determines the generalisability of the findings beyond the individual case (Yin, 2018). A multiple-case study approach as well as literal replication logic are employed to as a tactic to ensure external validity (Yin, 2018). Under this logic, replication means that the hypotheses were predicted to be true in all cases. The cases were selected based on varying speeds of industry innovation or product lifecycles, also called industry clockspeed. Even though these provided additional variety, the hypotheses were still expected to be true in all cases. Moreover, analytic generalisation was sought, in which the researcher aims to generalise from a case to a theory or conceptual model instead of a population (Yin, 2018). Due to the theory testing nature of this case study, generalisation was provided by falsifying existing theory on the contribution of PSSs to supply chain circularity (Tsang, 2014).

C.6.4 Reliability

The goal of reliability is to ensure the replicability of the case and its finding (Yin, 2018). This case study used the tactic of developing a case study database to increase the reliability of findings. To guide this process, Cranfield University's data management process was followed to ensure best practice and the auditability of the research.

C.7 References to Appendix C

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Appendix D – Interview Protocol

Follow-up questions:

- Could you please give an example?
- Could you please elaborate on that point? Explain this further?
- How important is that for your company?
- Why was this decision made?

Part I – Initiation

Objective: Explore Context/PSSs characteristics

Interviewee: Key account manager, services/ operations manager

- Could you give me a breakdown of the products this company manufactures?
- What type of service offerings and solutions do you offer for your products?
- When did you start offering the different business models and why? (Opinion)
- Who is the product owner in the offering?
- Who is the main user of the product in the offering?
- Who decides what products are used in the offering and how?
- When did you start offering the different business models and why – what was the driver? (Opinion)
- What are the contractual obligations in the offering?
- What type of pricing mechanism do you employ for the offering(s)? Why?
- How long do these contracts typically last?
- What is the focus of the offering (is it more on supporting products or solving specific needs of customers)?
- How do you adapt/customise the offering to the specific needs of the customer?
- How would you describe the intensity of the relationship with the customer?

Part II – Supply Chain Circularity

Objective: Determine circularity of product design

- What is the typical initial lifetime of a new product?
- How quickly do product and/or component designs typically change in your industry?
- How do you incorporate environmental aspects in the design of your products? (Opinion)
- How do you factor in end-of-life value recovery in the design of your products? If yes, why and when did this start? (Opinion)

- How, why do you incorporate servicing needs (i.e. maintenance & repairs) in the design of your products?
- Do you use any recycled or remanufactured components/materials in your product designs (% weight/ % of economic value)?
- What after-sales services (e.g. maintenance, repair, refurbish) that are carried out in delivering the offering? Why – when did this start? (Opinion)
- How do these activities help extend the product life? By how many months do they extend product life?
- What percentage of the products are returned to you at the end of their use? What happens to them?
- What is the technical potential for the products, components, and materials that you work with to be reused, remanufactured, and/or recycled?
- What typically happens to a product when it reaches its end-of-use/end-of-life?
- What is the economic value of product/components that you recover at end-of-life (% of new product)?
- How do you work towards improving the performance of these services?
- What happens to the materials after recycling? Are they fed into the new product feed? If yes, what percentage of the product (% value/ % weight) is made from secondary materials/ components?

Part III – Contextual factors

Objective: Clarify firm sustainability strategy, firm context

- How short/long are product lifecycles typically in your industry (speed of product innovation)?
- What markets are these offerings sold to (geography; B2B vs. B2C)?
- What are the main enablers and barriers for circular economy (product longevity/ closure of resource loops)? (Opinion)
- What factors does this depend upon? (Opinion)
- How can product longevity/ closure of resource loops/ resource efficiency increase the competitiveness of your offering in the future? What needs to happen for this, why? (Opinion)
- How would you describe the importance of sustainability for the company? (Opinion)
- How can product longevity/ closure of resource loops/ resource efficiency increase the competitiveness of your offering in the future? What needs to happen for this, why? (Opinion)