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Challenges in supply chain redesign for the Circular Economy: a literature review and a multiple case study

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Despite companies face several challenges when redesigning their supply chain for the Circular Economy, the literature lacks a systematisation of such challenges and of the ways to overcome them. Through a systematic literature review, this paper identifies and systematises 24 challenges that may hamper a supply chain redesign for the Circular Economy. Sixteen among these challenges are well known from research in related topics. On the contrary, the remaining eight are relatively new or take a different relevance within the Circular Economy context. A multiple case study in the household appliance supply chain is carried out, to explore how these challenges appear in practice and how companies may tackle them. The cases analysed involve actors at different supply chain levels, and findings suggest that a great degree of vertical integration by one actor in the supply chain is not a necessary condition for Circular Economy implementation. The empirical study, in conjunction with the literature analysis, leads to the development of a framework linking the challenges to specific levers that companies may pursue to overcome them. The framework can be seen as a reference for managers undertaking the path towards Circular Economy.

Keywords: circular economy; circular supply chain; circular business model; circular economy framework; sustainable supply chain; sustainability; closed-loop supply chain; household appliances

1. Introduction

Circular Economy (CE) has increasingly gained attention from academia, companies and policy-makers as a promising approach to jointly promote sustainability and competitiveness (Murray, Skene, and Haynes 2017). Among others, China, Japan, US and the European Union have issued policies to support the adoption of CE (Ghisellini, Cialani, and Ulgiati 2016; Winans, Kendall, and Deng 2017). However, besides this top-down approach, increased bottom-up efforts from companies are needed (Bressanelli, Perona, and Saccani 2019).

CE differs from the linear economy, i.e. the traditional way in which goods are produced, sold and disposed of, since it decouples economic growth from resource extraction and environmental losses (Elia, Gnoni, and Tornese 2017). Therefore companies who decide to redesign their supply chain for CE may obtain environmental (Genovese et al. 2017), social (Ongondo et al. 2013) and economic benefits (Cucchiella et al. 2015). Supply chain management and configuration activities play a major role in this regard. For instance, through a Life Cycle Assessment, it has been demonstrated that circular supply chains for insulation materials – in which waste is utilised as raw materials – reduce the emissions of Carbon Dioxide by 60% (Nasir et al. 2017). Moreover, introducing a reverse logistics for the collection and renovation of WEEE in Europe has the potential to generate revenues of about 2.15 billion euro through electronic waste recycling (Cucchiella et al. 2015).

However, several obstacles may prevent the achievement of these benefits, making the transition to CE far from obvious (van Loon, Delagarde, and Van Wassenhove 2018). For instance, the literature widely recognises the uncertainties about quantity, quality and timing of product returns that arise in closed-loop supply chains, transferring such uncertainties in, for instance, capacity planning for renovation activities such as remanufacturing (Linder and Williander 2017).

Despite their relevance in such an early stage of CE maturity by companies, the literature still lacks a systematic analysis of the challenges faced when redesigning the supply chain according to CE. Consequently, there is little knowledge on how to overcome these obstacles. To fill this gap, this paper carries out a systematic literature review about the challenges connected to supply chain redesign for CE, combined with a case-based research. More specifically, 24 challenges (either entirely new or related to well-established domains that are also part of the CE approach) are pointed out from the literature and grouped into seven categories. Then, the case studies provide insights on how these challenges appear in practice and

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*Corresponding author. Email: g.bressanelli002@unibs.it can be faced by companies. Thus, a set of levers to tackle these challenges is outlined. The levers have been linked to the 24 challenges in a conceptual framework.

The remainder of this paper is organised as follows. Section 2 describes the context of the study, its aim and the research methodology. Section 3 provides the findings of the systematic literature review, while Section 4 presents the case studies. then, in Section 5, a discussion of case studies findings is carried out, in the light of the literature, and a framework is proposed. Finally, concluding remarks, limitations and future research directions are drawn in Section 6.

2. Research process and method

2.1. Background: Circular Economy and supply chains

The Ellen MacArthur Foundation (2012) described CE as a 'system restorative and regenerative by design'. Since then, the academic interest on CE has been spreading. Literature reviews about CE have been published in recent years, but a common and widely agreed definition of CE is missing (Tecchio et al. 2017). Tukker (2015) reviewed the literature on product-service systems focusing on their role in the achievement of a CE based on resource efficiency. He pointed out the reasons why CE is not widely implemented yet, especially in the Business-to-Consumer (B2C) sector. Loss of users' control over products, financial and operational risks are among the main barriers in this regard. Ghisellini, Cialani, and Ulgiati (2016) examined the implementation of CE with a special focus on its origins, basic principles, limitations, advantages and disadvantages at different levels of implementation, from the single company to the regional or national point of view. According to their research, CE provides a reliable framework to transform current business models towards sustainable development. Lewandowski (2016) reviewed the literature in order to identify and classify CE characteristics according to a business model structure. Moving from that, he conceptualised an extended framework for the design and adoption of CE business models. Lieder and Rashid (2016) reviewed the literature about the application status of CE in manufacturing contexts. The study proposes a comprehensive CE framework linking together economic benefits, environmental impacts and resource scarcity issues. The work concludes that for succeeding in CE implementation, a combination of top-down (i.e. efforts from public institutions) and bottom-up approaches (i.e. efforts from industries) is required. Masi, Day, and Godsell (2017) reviewed the literature in order to find a common ground underpinning the implementation of CE at the supply chain level, identifying drivers and enablers. Finally, Geissdoerfer et al. (2017) reviewed the extant literature to highlight similarities, differences and relationships between CE and sustainability concepts.

According to the Ellen MacArthur Foundation (2012), a transition towards CE involves four fundamental building blocks: (i) to keep products, components and materials at their highest utility and value, several *circular product design* policies may be pursued, such as product life extension and eco-design (Mont 2008), material selection (Bakker et al. 2014) and Design-for-X techniques (Kane, Bakker, and Balkenende 2018); (ii) *servitised Business Models (BMs)* based on the provision of the function encourage take-back systems and circular product redesign (Kjaer et al. 2018), since manufacturers in that case retain products ownership. Leasing, sharing, pay-per-use and pay-per-result represent viable examples of servitised BMs (Tukker 2015); (iii) integrating *reverse logistics* into conventional supply chains may reduce waste and help companies making profits through the recovery of used products (Kazemi, Modak, and Govindan 2018). In this regard, CE involves 'renovation' activities such as repair, reuse, refurbishment, remanufacturing and recycling (Parajuly and Wenzel 2017). When feasible, a hierarchy among these activities should be followed: reuse is preferable to recycling, since much of the value remains intact (Kalverkamp, Pehlken, and Wuest 2017); (iv) a number of *enablers and favourable conditions* may support a CE transition, such as collaboration (Elia, Gnoni, and Tornese 2017), digital technologies (Bressanelli et al. 2018), users' awareness towards sharing, regulation, financing and the creation of a market for secondary products (Saidani et al. 2018).

As suggested by the four building blocks, the CE concept is highly multidisciplinary and comprehends areas and streams of research that existed well before the term 'Circular Economy' was coined (Geissdoerfer et al. 2017). As mentioned above, however, a common and widely agreed definition of CE is missing. We therefore provide a definition of CE based on the works by the Ellen MacArthur Foundation (2012), Braungart, McDonough, and Bollinger (2007) and Kirchherr, Reike, and Hekkert (2017). For the purpose of this paper, CE is defined as

> an economic system restorative and regenerative by design, implemented by one or more supply chain actors through one or more of the four building blocks (circular product design, servitised business models, reverse logistics and enablers) in order to replace the end-of-life concept with reducing, alternatively reusing, recycling and recovering materials in production, distribution and consumption processes, for both technical and biological materials, with the aim to accomplish sustainable development.

Our definition suggests a broad interpretation of the CE concept, based on the business practice. From a supply chain perspective, in fact, it is quite uncommon that a company (e.g. the manufacturer or a distributor) redesigns the entire value chain to adopt CE. Vertical integration and control over the production, distribution and consumption processes by one single actor is often limited, so that many current CE endeavours actually encompass only one or few of the building blocks, sometimes trying to involve an ecosystem of partners carrying out different value chain activities. Therefore our definition considers as ‘CE initiatives’ also the ones where relevant actions are undertaken only on one or few of the abovementioned building blocks to achieve sustainability (e.g. on circular product design but not on servitised BMs, or *vice versa*). In fact, even in notable CE endeavours covered by the specialised press, this approach is much more common than a thorough adoption of the four building blocks coupled by a comprehensive supply chain perspective. For instance, H&M has recently changed its mission statement to ‘become 100% circular’, and it is currently exploring solutions to create a closed-loop supply chain for textiles, tightening a partnership with a reverse logistics service provider and also directly working at the design stage, especially regarding the material choice (H&M Group 2017). However, no action towards the adoption of servitised BMs is planned. Conversely, the Dutch startup MUD jeans offers jeans and other clothes under a leasing contract, so to collect and recycle them when they reach the end-of-use. However, the company has little control over the manufacturing and design stages of clothing (Ellen MacArthur Foundation 2018). On the other hand, Philips has launched a CE initiative where lighting is offered as-a-service (servitised BM), LED lightings are designed to enhance preventive maintenance and upgrades, and the retained ownership throughout the contract period entails the take back of the lightings at end-of-life (Philips 2015). The latter is one of the very few cases where, in order to develop and govern an actual end-to-end CE project, the same actor is responsible for product design and manufacturing (in order to control the design characteristics and the direct logistics impact), the distribution and sales (in order to build up and deliver new servitised BMs), and the after-sales and end-of-life processes (in order to enhance lifecycle duration and carry out renovation activities). Since most of the cases – such as H&M – are to date ‘incomplete’ compared with such a comprehensive perspective, we believe that all initiatives that act in one or more of the CE directions (i.e. the four building blocks) and have a sustainable development aim (Kirchherr, Reike, and Hekkert 2017) should be considered ‘circular’ endeavours, and therefore fall into the CE definition provided above.

2.2. Research gap and methodology

As mentioned above, supply chain redesign for CE implies a systemic and holistic approach, encompassing an adequate redesign of products, of servitised BMs, of the actors and flows encompassed, and of endogenous as well as exogenous enablers.

However, such a supply chain redesign poses several challenges. Some of the challenges have been pointed out in studies about closed loop supply chains (Bouzon, Govindan, and Rodriguez 2018; Singh and Ordoñez 2016) or servitisation (Alghisi and Saccani 2015), but the analysis has been limited to those specific disciplines, while previous research on CE challenges focused either on a particular industrial sector (Densley Tingley, Cooper, and Cullen 2017; Franco 2017; Govindan, Madan Shankar, and Kannan 2016; Khodier, Williams, and Dallison 2018), on a geographical context (Geng and Doberstein 2008; Li and Yu 2011; Shahbazi et al. 2016; Whalen, Milios, and Nussholz 2018), or on a specific firm category, such as social enterprises or SMEs (Ongondo et al. 2013; Rizos et al. 2016). Overall, a systemic and holistic categorisation of the challenges for supply chain redesign for CE has not been proposed yet in the literature. Thus, this paper aims to fill this gap, and has two objectives:

(i) To provide a categorisation of CE challenges for supply chain redesign through a systematic literature review;
(ii) To identify levers that could be used to overcome these challenges.

To achieve these objectives, the scientific literature was scrutinised in a systematic way (Tranfield, Denyer, and Smart 2003), so to point out the challenges that come into play when supply chains are redesigned for CE. The literature review was conducted on the Scopus database, while the selection procedure was designed following the guidelines drafted by Seuring and Gold (2012). A structured search was carried out, combining the keywords ‘challenge’, ‘obstacle’ and ‘barrier’ with terms identifying CE, i.e. ‘circular economy’, ‘closed loop supply chain’, and ‘green supply chain’. All the possible combinations between the two sets of keywords were scanned and the list of papers obtained from the searches was refined following the process depicted in Figure 1.

The keyword search led to an initial set of 896 entries, corresponding to 733 unique documents originally written in English. From this set, only papers that appeared in journals with an Impact Factor according to Thomson Reuters Journal Citation Report have been selected, to ensure the quality and relevance of the analysed studies (Geissdoerfer et al. 2017). Thus, 268 papers were scrutinised by initially reading the title and the abstract. When title and abstract evaluations were unclear, the full paper contents were scrutinised. The following criteria were defined to select papers for the literature review:

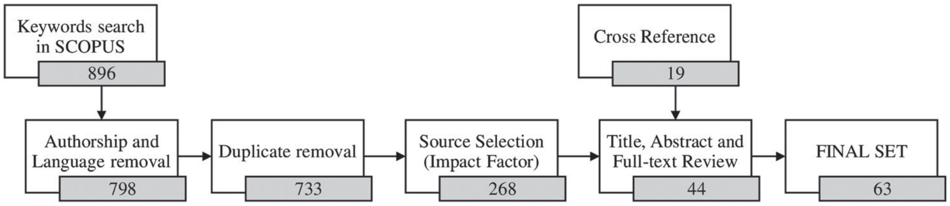

Figure 1. Systematic literature review process.

- the paper addresses and discusses the challenges about the adoption of CE into supply chains, AND
- the paper focuses on a single company and/or the supply chain level. Studies addressing the ‘macro’ level only (e.g. national impacts) were therefore discarded, AND
- the paper deals with technological cycles of industrial materials (Braungart, McDonough, and Bollinger 2007). Studies addressing only the biological ones were discarded.

Forty-four papers were selected based on these criteria. Lastly, in order to overcome possible limitations of database search, the set of papers has been complemented by cross-referencing (Seuring and Gold 2012). This step led to the inclusion of 19 additional papers. Consequently, 63 papers have been selected and analysed in detail.

To address the second objective, the set of challenges has been investigated empirically, in order to explore how companies are facing them and to discuss the findings in the light of the literature background. Given that CE is still a novel phenomenon (Murray, Skene, and Haynes 2017) and the exploratory nature of the research, the case study methodology was considered suitable (Yin 2009). To increase the external validity, a multiple case study, i.e. a case research where more than one company study is carried out, has been conducted (Voss, Tsikriktsis, and Frohlich 2002). Accordingly, a research protocol was developed in order to enhance the validity and the reliability of the research, encompassing the overall design of the case study, the data collection, the data analysis as well as the results formalisation (Yin 2009). A visual overview of the research steps conducted in the multiple case study is provided in Figure 2. Moreover, a simplified version of the research protocol adopted is provided in the Appendix.

Cases were selected according to a judgmental sampling technique and following two main criteria: (a) cases should concern companies having undertaken a CE project, involving the redesign of their value and/or supply chain; (b) cases should provide an adequate representation of different life cycle phases, supply chain actors, and altogether cover all the four CE building blocks. In order to ensure the homogeneity of results, it was decided to select only cases regarding a specific industrial sector. The Household Appliance (HA) supply chain – and in particular the Washing Machines (WM) industry – was chosen, for being a promising arena for the adoption of the CE paradigm (Ellen MacArthur Foundation

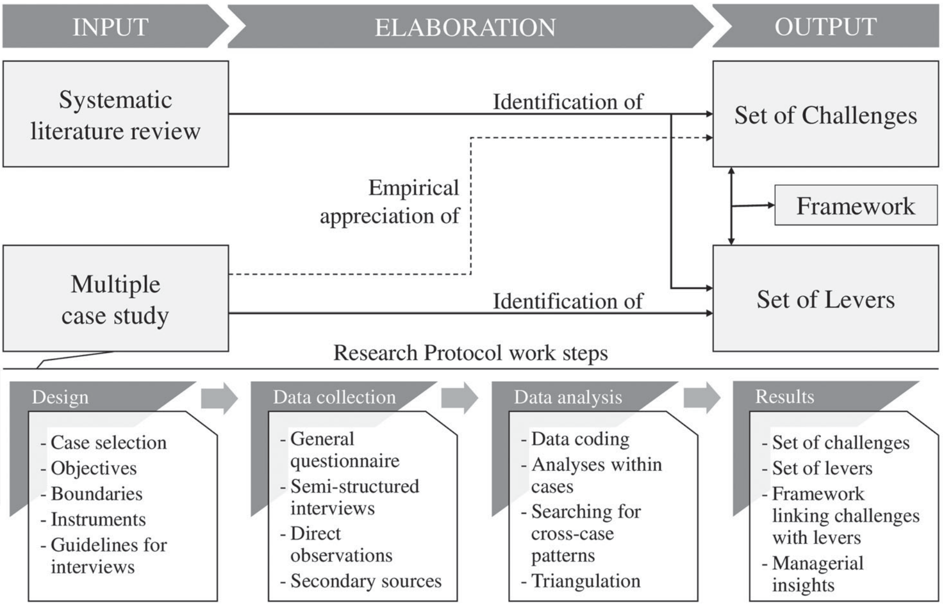

Figure 2. Research steps.

Table 1. Case companies overview.

	Company *Alpha*	Company *Beta*	Company *Gamma*	Company *Delta*
Role	Retailer (startup)	Spare parts distributor	Self-service laundry chain franchiser	HA manufacturer
Activities involved	Product-as-a-service provision	Reconditioning and refurbishment	Self-service laundry digitisation	Design and manufacturing
Main CE Building Block involved	Servitised BMs	Reverse logistics	Enablers (digital technologies)	Circular product design
Turnover 2016 [million €]	$< < 1$	~ 15	~ 6	> 1000
Size 2016 [number of employees]	< 10	~ 20	~ 20	$> 10,000$
Number of interviews and role of respondents	2 interviews: CEO and founder, SW development manager	3 interviews: CEO, Managing director, Reconditioning manager	3 interviews: CEO and founder, Technical director, Marketing manager	2 interviews: Innovation manager, Sustainability team manager

2012). Four (anonymous) companies accepted to participate in the study. Table 1 provides the main descriptive information concerning the four cases.

Following the research protocol, a questionnaire was used to gather general information about the context in which each company operates, such as the turnover, the number of employees, and so forth. Then, specific information was gathered through semi-structured interviews, which generally lasted between one and two hours. Each interview was carried out following the 'guidelines for interview', a document included in the research protocol that outlines the topics to be covered by the interviewers, the questions to be asked, and the data to be collected (see the Appendix). More specifically, the list of challenges emerged from the literature review (see Section 3) informed the definition of these guidelines. Through the interviews, we investigated whether the 24 challenges have occurred in the cases. Also, the background on the levers to overcome CE challenges described in Section 3.8 was used to draft the guidelines, so to assess whether the course of actions undertaken by the case companies could be assimilated to the categories mentioned in the literature or not.

To enhance the study reliability, different company roles were consulted, as reported in Table 1, and more than one researcher took part to the interviews. The interviews were transcribed, coded and sent back to respondents for validation. Triangulation with secondary sources (company documentation, websites, etc.) has been carried out, to enhance construct validity (Voss, Tsikriktsis, and Frohlich 2002). The analysis of the CE initiatives carried out by the four cases was made through the lens of the four building blocks of CE, to investigate whether and how circular product design, servitised BMs, reverse logistics and enablers have been implemented by the case companies. The findings from both the multiple case study and the literature analysis have been used to fill the conceptual framework designed in Section 5, where the 24 challenges have been matched with a set of potential levers to overcome them.

3. Literature review: a systematisation of Circular Economy challenges and levers

As mentioned before, studies about CE have not carried out a systemic categorisation of the challenges entailed by supply chain redesign for CE. This paper, adopting a comprehensive perspective on CE, identifies 24 challenges about CE supply chain redesign from the analysis of the 63 papers selected for the literature review. The challenges were classified into seven categories based on their similarities and meaning. The categories are *Economic and financial viability*, *Market and competition*, *Product characteristics*, *Standards and regulation*, *Supply chain management*, *Technology*, and *Users' behaviour*. These seven categories were obtained inductively from the content analysis of the literature and were also inspired by previous classification schemes. In the next subsections, the challenges in each of the seven categories are briefly described. The description is supported by Tables 2–8, providing literature references and an anecdotal example for each challenge. It is important to point out that several challenges stem from well-established research streams such as closed-loop supply chain or servitisation, and thus were already known before the term 'Circular Economy' was coined. However, these challenges are still likely to appear when CE initiatives are undertaken, as the reviewed literature suggests, and therefore are included in the list. Eight out of the 24 challenges, instead, are relatively new with CE or take a different or extended meaning or relevance than in the past within the CE context. This aspect is also illustrated in the next subsections, as well as in the column 'origin' of Tables 2–8.

Table 2. Economic and financial viability challenges.

ID	Challenge	Description	Origin	Example (anecdotal)	References
1	Time mismatch between revenue and cost streams	Servitised Business Models (BMs) usually decouple-in-time the relation between costs incurred from manufacturing processes and revenue streams from customers. This, in turn, results in longer payback time for the manufacturer/supplier	Well-established challenge of servitisation	*Cars*– In e.g. a car sharing BM, manufacturers have to finance the upfront production costs of the cars, while they are paid back based on their usage, thus postponing the economic break-even point	Barquet et al. (2013); Metta and Badurdeen (2013); Neely (2008); Rizos et al. (2016); Shahbazi et al. (2016); Tukker (2015)
2	Financial risk	In traditional sales-oriented BMs, the financial risk is shifted to the user when the product is sold. Conversely, in servitised BMs, this risk remains with the supplier even after the first transaction	Well-established challenge of servitisation	*Printers*– Under a pay-per-copy BM, the manufacturer (or provider) finances the entire solution, but there is the financial risk that customers interrupt in advance the signed contract	Baines and Lightfoot (2013); Krikke (2011); Lewandowski (2016); Linder and Williander (2017); Mont (2008); Tukker (2015)
3	Operational risk	In servitised BMs, also the operational risk (i.e. costs of product damages, maintenance, repair, etc.) remains with the supplier	Well-established challenge of servitisation	*Printers*– Under a pay-per-copy BM, if a printer breaks down, the supplier bears the repair cost, not the user (who pays a fixed cost that includes maintenance)	Baines and Lightfoot (2013); Barquet et al. (2013); Krikke (2011); Linder and Williander (2017); Mont (2008); Saidani et al. (2018); Tukker (2015)

3.1. Economic and financial viability

Three specific challenges have been identified for this category. They all refer to the adoption of servitised BMs, where the function is sold instead of the product itself, through different forms (e.g. leasing, pay-per-x, pay-per-performance, sharing, etc.).

First, when companies decide to adopt servitised BMs, they must take into account a *time mismatch between revenue and cost streams*. In fact, providers shifting their offering from selling the product ownership to selling the function have to finance the capital costs of the solution, since revenue streams are postponed over time (Barquet et al. 2013). In turn, this results in longer payback time, questioning the economic and financial viability of CE implementation projects.

Moreover, when products are offered through servitised BMs, *financial* and *operational risks* are transferred from users to providers (Baines and Lightfoot 2013). Providers are financially exposed to the risks of early suspensions of the contract by customers and, in several cases, they are responsible for the operational costs of the solution offered, e.g. due to maintenance activities. For a more detailed analysis of financial and operational risks, see, e.g. Neely (2008).

3.2. Market and competition

The second category encompasses challenges related to market and competition. In general, companies may decide not to offer circular products (e.g. remanufactured ones, or products designed-to-last) because they fear this would reduce primary sales (van Loon and Van Wassenhove 2017). This phenomenon is also called market *cannibalisation* (Linder and Williander 2017), and it assumes a specific meaning and relevance for CE. First, the risk of cannibalisation comes along with any product innovation, where a new product range or the offering of remanufactured products can 'cannibalise' the sales of other product ranges (Krikke 2011). In CE, however, cannibalisation concerns also a time dimension: the longer product lifecycle thanks to 'design-to-last' practices or e.g. predictive maintenance leads to a lower product substitution rate than in the linear economy. A company will thus reduce its future sales, potentially putting at risk its survival in the long term (Lewandowski 2016; Linder and Williander 2017). Consequently, the durability of CE products should be addressed also taking into account such cannibalisation risk, as for instance modelled in Steeneck and Sarin (2018).

When third parties are involved, supply chain issues related to *know-how access and Intellectual Property (IP)* arise, and may prevent the execution of maintenance or renovation activities (Kalverkamp, Pehlken, and Wuest 2017). For instance, original equipment manufacturers (OEMs) may limit the possibility for third parties to execute these activities, to protect

Table 3. Market and competition challenges.

ID	Challenge	Description	Origin	Example (anecdotal)	References
4	Cannibalisation	New 'circular' products (e.g. products designed to last longer) can cannibalise the existing ones, affecting the company revenue streams from traditional products and reducing the overall future sales of the company	It assumes a specific meaning and relevance, since in a CE cannibalisation concerns also a time dimension, due to increased lifecycle duration that reduces the sales of new (or even refurbished) products due to a lower substitution rate.	*Household appliances* – Long lasting appliances may substitute the sales of new appliances, leading to a cannibalisation of the new product offering	Bouzon, Govindan, and Rodriguez (2018); Kane, Bakker, and Balkenende (2018); Krikke (2011); Lewandowski (2016); Linder and Williander (2017); Mont (2008); Ongondo et al. (2013); O'Connell, Hickey, and Fitzpatrick (2013); Parajuly and Wenzel (2017); Tukker (2015); van Loon and Van Wassenhove (2017)
5	IP and know-how access	Activities (e.g. remanufacturing) accomplished by a third party (independent from a manufacturer) may lead to a loss of control by the manufacturer of the Intellectual Property (IP) embedded in the products. For the same reasons, manufacturers may hinder an easy access to spare parts, repair manuals and tools for third-party actors	Well-established challenge of value chain configuration	*Medical imaging equipment*– Due to highly competitive levels of IP protection in the field of medical equipment, service contracts in which a third party performs repair and maintenance, rather than in-house technicians, are difficult to achieve (Kane, Bakker, and Balkenende 2018)	Despeisse et al. (2017); Kane, Bakker, and Balkenende (2018); Mathiyazhagan et al. (2013); O'Connell, Hickey, and Fitzpatrick (2013); Rauer and Kaufmann (2015); Saidani et al. (2018); Sundin and Bras (2005); Whalen, Milios, and Nussholz (2018)
6	Brand Image	Activities (e.g. remanufacturing) accomplished by a third-party (independent of OEM), if not performed properly, will have a negative impact on the OEM brand image	Well-established challenge of value chain configuration	*Smartphone*– In the smartphone market, it is quite common that a third party performs repair and/or refurbishment. But, if the activity is not performed correctly, it is the brand of the OEM that is affected	Gutowski et al. (2011); Kalverkamp, Pehlken, and Wuest (2017); O'Connell, Hickey, and Fitzpatrick (2013); Sundin and Bras (2005); Whalen, Milios, and Nussholz (2018)

their IP, through proprietary technology or by preventing the access to technical manuals, procedures, spare parts and specific tools (Kane, Bakker, and Balkenende 2018). While this protects the OEM technological/competitive advantage (by limiting the access to such resources and activities to the OEM itself or authorised partners), it may prevent the application of CE related activities on a large portion of the installed base.

Finally, renovation activities performed by third parties may also affect the OEM *brand and reputation* if not performed correctly, especially when OEMs exert little or no control over their execution (O'Connell, Hickey, and Fitzpatrick 2013).

3.3. Product characteristics

Circular products are designed to last, rather than for use-and-throw-away: thus, they might be unable to respond to *fashion changes*, resulting unattractive for a part of the customer base (Linder and Williander 2017), in particular in the B2C sectors. This challenge is relatively new, since in conventional linear contexts the competition among products is based on aspects such as price, promotion and so forth, while in the large majority of case the product duration does not differentiate in a substantial way competing products. For instance, when comparing two car purchase options, the customer will assume the

Table 4. Product characteristics challenges.

ID	Challenge	Description	Origin	Example (anecdotal)	References
7	Fashion change	Products designed-to-last are unable to respond to fashion changes	It assumes a specific meaning in CE, since typically the competition among products is based on other characteristics than duration (price, promotion, etc.)	*Clothes*– Users may be reluctant to buy clothes designed to last, due to frequent fashion changes that these products are unable to respond	Franco (2017); Linder and Williander (2017); Tukker (2015)
8	Product complexity	The proliferation of new materials as well as the growth of product complexity (e.g. Bill-of-Material) increase the difficulties in managing recovering and recycle processes.	Well-established challenge of reverse logistics and renovation	*Plastics*– In the plastics industry, the number of new polymers has continued to grow in the past decades, increasing exponentially the material complexity and the difficulties in plastics recovering and recycling	Despeisse et al. (2017); Franco (2017); Govindan, Madan Shankar, and Kannan (2016); Khodier, Williams, and Dallison (2018); Metta and Badurdeen (2013); Singh and Ordoñez (2016)
9	Product (mass) customisation	Mass customisation pushes towards personalised products, which leads to a higher complexity when products are disassembled for remanufacturing	Well-established challenge of reverse logistics and renovation	*Medical devices* – Usually, personal medical devices are manufactured around each individual patient's characteristics. Thus, reuse and remanufacturing of these customised products is often challenging	Despeisse et al. (2017); Franco (2017); Govindan, Madan Shankar, and Kannan (2016); Kane, Bakker, and Balkenende (2018); Khodier, Williams, and Dallison (2018); Metta and Badurdeen (2013); Singh and Ordoñez (2016)

useful life to be quite similar, while cases in which one option promises a double life duration than the alternatives are more than rare.

Moreover, as *products or product ranges complexity* increases, renovation activities might become more difficult (Despeisse et al. 2017). This is quite evident in e.g. the plastics industry, where the number of polymers proliferated in the past decades (Huysman et al. 2017). *Product customisation* has a similar impact, since it reduces the attractiveness of CE renovation activities. Finally, *mass customisation* pushes towards even more personalised products (Mont 2008), thus increasing the difficulties in renovation processes and narrowing down the market for products issued from such activities (Metta and Badurdeen 2013).

3.4. Standards and regulation

Existing taxation systems as well as financial incentives are frequently not aligned with the adoption of the CE paradigm (Al Zaabi, Al Dhaheri, and Diabat 2013). Indeed, *taxation and policy instruments misalignment* may hinder the implementation of CE (Mathiyazhagan et al. 2013). For instance, to promote CE, non-renewable resources like carbon-based fuels should have taxation levels higher than renewable ones such as labour, but frequently this does not occur (Stahel 2013). Moreover, current regulatory frameworks usually focus on recycling rather than on reuse (Kissling et al. 2013), thus not following the hierarchy among CE activities that would preserve the most of the intrinsic product value (Kane, Bakker, and Balkenende 2018). Scholars also point out the lack of adequate financial incentives as a factor that hinder CE practices in supply chains (Stahel 2013).

Furthermore, a commonly recognised system of *measures, metrics and indicators* to monitor CE progress is missing (Govindan, Madan Shankar, and Kannan 2016). For instance, most of the existing micro and macro indicators – such as gross domestic product (GDP) or the company turnover – were built around the linear economy perspective, aiming to maximise throughput and sales. CE, on the other hand, shifts the focus from a purely volume-driven economy towards a more conservative one, where the stock of products, materials and resources is optimised, rather than their flow (Stahel 2013). This lack of measures has led researchers to develop ad hoc indicators to monitor the progress of CE activities inside companies (Park and Chertow 2014).

Table 5. Standards and regulation challenges.

ID	Challenge	Description	Origin	Example (anecdotal)	References
10	Taxation and incentives	Existing taxation systems, policies as well incentives, are not aligned with the adoption of the CE paradigm	It assumes a specific meaning in CE, since taxation, incentives and regulation systems should be aligned with CE principles to promote CE	*General*– Non-renewable resources (e.g. carbon, oil, etc.) have often taxation levels comparable or lower than renewable ones. Moreover, labour generally has higher taxation rates than raw materials. In addition, existing national and international regulations mainly focus on recycling, rather than on other CE renovation activities such as reuse.	Al Zaabi, Al Dhaheri, and Diabat (2013); Barquet et al. (2013); Bouzon, Govindan, and Rodriguez (2018); Geng and Doberstein (2008); Govindan et al. (2014); Govindan, Madan Shankar, and Kannan (2016); Kalverkamp, Pehlken, and Wuest (2017); Kane, Bakker, and Balkenende (2018); Kissling et al. (2013); Li and Yu (2011); Linder and Williander (2017); Liu et al. (2017); Masi, Day, and Godsell (2017); Mathiyazhagan et al. (2013); Ongondo et al. (2013); Pitkänen et al. (2016); Prosman, Waehrens, and Liotta (2017); Ranta et al. (2018); Rauer and Kaufmann (2015); Rizos et al. (2016); Saidani et al. (2018); Shahbazi et al. (2016); Stahel (2013); Tecchio et al. (2017); van Loon and Van Wassenhove (2017); Walker, Di Sisto, and McBain (2008); Wang et al. (2016); Whalen, Milios, and Nussholz (2018); Winans, Kendall, and Deng (2017); Wübbeke and Heroth (2014); Xue et al. (2010)
11	Measures, metrics, indicators	Existing indicators were built around the concept of Linear Economy, with the aim to maximise throughput. CE requires shifting the focus from a purely volume-driven economic perspective to a more comprehensive one, encompassing economic, environmental and social dimensions	It assumes a specific meaning in CE, since measures, metrics and indicators should be aligned with CE principles to promote CE	*Gross Domestic Product GDP*– The GDP metric (macro-economic indicator) measures the total output of a national economy, i.e. a financial flow over a time-period. CE, on the other hand, is about the optimisation of the stock. The adoption of the CE paradigm, therefore, is likely to result in a reduction of GDP, thus implying a negative impact on the economy as a whole according to the currently used metrics	Al Zaabi, Al Dhaheri, and Diabat (2013); Govindan et al. (2014); Govindan, Madan Shankar, and Kannan (2016); Huysman et al. (2017); Masi, Day, and Godsell (2017); Mathiyazhagan et al. (2013); Metta and Badurdeen (2013); Park and Chertow (2014); Rauer and Kaufmann (2015); Shahbazi et al. (2016); Stahel (2013); Tecchio et al. (2017); Wang et al. (2016)
12	Lack of standards	Standards regarding CE processes, activities, materials, etc. are generally missing	It assumes a specific meaning in CE, since standards should be aligned with CE principles	*Materials for 3D Printing*– Standards regarding e.g. the material composition of inputs in Additive Manufacturing processes have not been defined yet	Al Zaabi, Al Dhaheri, and Diabat (2013); Bouzon, Govindan, and Rodriguez (2018); Despeisse et al. (2017); Kissling et al. (2013); Liu et al. (2017); Ranta et al. (2018); Rauer and Kaufmann (2015); Tecchio et al. (2017)

Table 6. Supply chain management challenges.

ID	Challenge	Description	Origin	Example (anecdotal)	References
13	Return flows uncertainty	Uncertainty about quantity, mix, quality, time and place of returns of end-of-use products decreases the probability of achieving an economic scale and creates difficulties in capacity planning. Illegal forms of disposal reduce the amount of products collected and treated at end-of-use, thus increasing this uncertainty	Well-established challenge of reverse logistics and renovation	*Waste of Electrical and Electronic Equipment (WEEE)*– In WEEE system, the quantity (and the right mix) of end-of-use products that will be collected is not known a priori, as well as their quality, the time and the place of collection	Bouzon, Govindan, and Rodriguez (2018); Cucchiella et al. (2015); Densley Tingley, Cooper, and Cullen (2017); Despeisse et al. (2017); Franco (2017); Govindan, Madan Shankar, and Kannan (2016); Gutowski et al. (2011); Kalverkamp, Pehlken, and Wuest (2017); Kissling et al. (2013); Kumar and Putnam (2008); Linder and Williander (2017); Liu et al. (2017); Metta and Badurdeen (2013); Ongondo et al. (2013); O'Connell, Hickey, and Fitzpatrick (2013); Ranta et al. (2018); Richter and Koppejan (2016); Rizos et al. (2016); Saidani et al. (2018); Shahbazi et al. (2016); Singh and Ordoñez (2016); Ueberschaar et al. (2017); Wakolbinger et al. (2014); Whalen, Milios, and Nussholz (2018); Winans, Kendall, and Deng (2017); Wojanowski, Verter, and Boyaci (2007); Wübbeke and Heroth (2014)
14	Transportation and infrastructure	Due to the installed base geographical dispersion, CE would drastically increase transportation activities and costs if all the products have to be sent back to producers or specialised sites for refurbishing, remanufacturing, etc.	Well-established challenge of reverse logistics and renovation	*Washing machines*– In order to refurbish and remanufacture washing machines, they must be collected from users' houses, thus increasing transportation	Bakker et al. (2014); Cucchiella et al. (2015); Despeisse et al. (2017); Krikke (2011); Mont (2008); Ongondo et al. (2013); Whalen, Milios, and Nussholz (2018); Winans, Kendall, and Deng (2017)
15	Availability of suitable supply chain partners	Companies who decide to move towards CE often experience difficulty in finding appropriate supply chain partners, with appropriate skills and a CE approach	Well-established challenge of value chain configuration	*Automotive*– In the automotive sector, it is often difficult to find partners who, besides performing CE activities, fulfil also strict environmental parameters required to accomplish the CE strategy envisaged by an OEM	Bakker et al. (2014); Barquet et al. (2013); Bouzon, Govindan, and Rodriguez (2018); Despeisse et al. (2017); Geng and Doberstein (2008); Govindan et al. (2014); Govindan, Madan Shankar, and Kannan (2016); Lieder and Rashid (2016); Linder and Williander (2017); Masi, Day, and Godsell (2017); Mathiyazhagan et al. (2013); Ongondo et al. (2013); Rauer and Kaufmann (2015); Rizos et al. (2016); Sundin and Bras (2005); Tukker (2015); Walker, Di Sisto, and McBain (2008); Wang et al. (2016); Whalen, Milios, and Nussholz (2018)

(*Continued*)

Table 6. Continued.

ID	Challenge	Description	Origin	Example (anecdotal)	References
16	Coordination and information sharing	CE requires a close collaboration and information exchange among the different tiers of the supply chain, which may not be achieved especially within global configurations. This can be due to several reasons such as competition among supply chain tiers, information sensitivity, IT system integration, poor planning of activities, etcetera.	Well-established challenge of value chain configuration	*WEEE* – In WEEE system, collection and valorisation of end-of-use products may be enhanced by a better coordination and information sharing among the several actors (e.g. users, scavengers, smelters, etc.)	Al Zaabi, Al Dhaheri, and Diabat (2013); Bouzon, Govindan, and Rodriguez (2018); Densley Tingley, Cooper, and Cullen (2017); Geng and Doberstein (2008); Govindan et al. (2014); Kalverkamp, Pehlken, and Wuest (2017); Kumar and Putnam (2008); Li and Yu (2011); Masi, Day, and Godsell (2017); Mathiyazhagan et al. (2013); Pitkänen et al. (2016); Prosman, Waehrens, and Liotta (2017); Rauer and Kaufmann (2015); Rizos et al. (2016); Saidani et al. (2018); Walker, Di Sisto, and McBain (2008); Winans, Kendall, and Deng (2017); Wübbeke and Heroth (2014)
17	Product traceability	Product traceability improves collection and renovation processes, but often information systems provide an inadequate support. Several information should be available and easy accessible to the relevant supply chain partners in order to improve the efficiency of return flows and end-of-use activities, as well as to improve the capability to make accurate forecasts	Well-established challenge of value chain configuration	*WEEE* – In many EU countries, WEEE collection and renovation activities are not traced with appropriate IT systems and devices (e.g. RFID, IoT sensors, etc.). For instance, when WEEE are collected, information regarding the ‘status’ of products are not gathered and therefore renovation activities cannot be planned accurately	Densley Tingley, Cooper, and Cullen (2017); Despeisse et al. (2017); Franco (2017); Lewandowski (2016); Parajuly and Wenzel (2017); Rizos et al. (2016); Saidani et al. (2018)
18	Cultural issues (linear mind-set)	Internal resistance to change, especially given the prevailing linear mind-set and structures in industries (also referred to as the ‘Linear lock-in’), limited awareness and commitment (from both top management and employees)	It assumes a specific meaning and relevance in a CE, since ad-hoc actions to contrast cultural issues should be designed in accordance with CE principles	*Smartphones*– Despite several studies have shown the economic feasibility of CE solutions in the smartphone sector (Ellen MacArthur Foundation 2012), companies such as Huawei still perceive the business impact of CE on its turnover as low (Ranta et al. 2018)	Al Zaabi, Al Dhaheri, and Diabat (2013); Densley Tingley, Cooper, and Cullen (2017); Franco (2017); Geng and Doberstein (2008); Govindan et al. (2014); Govindan, Madan Shankar, and Kannan (2016); Lieder and Rashid (2016); Masi, Day, and Godsell (2017); Mathiyazhagan et al. (2013); Pitkänen et al. (2016); Ranta et al. (2018); Rauer and Kaufmann (2015); Rizos et al. (2016); Shahbazi et al. (2016); Walker, Di Sisto, and McBain (2008); Wang et al. (2016); Xue et al. (2010)

Finally, *a lack of standards* regarding CE processes, activities and materials is widely acknowledged in the literature (Tecchio et al. 2017). For instance, standards regarding the input composition in Additive Manufacturing technologies for most metals and polymeric materials have not been defined yet (ASTM 2017).

Table 7. Technology challenges.

ID	Challenge	Description	Origin	Example (anecdotal)	References
19	Eco-efficiency of technological processes	Renovation processes (especially recycling) may be inefficient from a technological perspective, causing losses and cross-contamination of materials. Moreover, they can be very expensive compared to the linear production from raw materials	Well-established challenge of reverse logistics and renovation	*Electrical and Electronics Equipment process*– The typical WEEE recycling process reckons on a pre-processing step, based on a ‘shred and separate’ approach. This first step results in losses and materials cross-contamination	Baxter, Aurisicchio, and Childs (2017); Bouzon, Govindan, and Rodriguez (2018); Despeisse et al. (2017); Franco (2017); Geng and Doberstein (2008); Govindan et al. (2014); Govindan, Madan Shankar, and Kannan (2016); Khodier, Williams, and Dallison (2018); Li and Yu (2011); Liu et al. (2017); Masi, Day, and Godsell (2017); Mathiyazhagan et al. (2013); Parajuly and Wenzel (2017); Pitkänen et al. (2016); Saidani et al. (2018); Shahbazi et al. (2016); Ueberschaar et al. (2017); Wang et al. (2016); Winans, Kendall, and Deng (2017); Wübbeke and Heroth (2014); Xue et al. (2010)
20	Product technology improvement	Products designed to last would be unable to participate in the continuous technology improvements processes	Well-established challenge of reverse logistics and renovation	*Washing machines*– Prolonging the lifespan of energy or consumable intensive products (such as washing machines) leads to losing the chance of (i.) participating in the continuous efficiency gains in energy or water consumption offered by new washing machines (ii.) taking advantage of more material-efficient eco-design	Bakker et al. (2014); Kane, Bakker, and Balkenende (2018); Kumar and Putnam (2008); Murray, Skene, and Haynes (2017); Saidani et al. (2018)
21	Data privacy and security	Concerns about privacy and data security inhibit collection of products when they reach the end-of-use. Appropriate data-clear activities must be guaranteed.	It assumes a specific meaning and relevance for CE, since generally privacy issues do not emerge at the end-of-use	*Smartphones*– Many users are reluctant to return their used smartphones, since they fear that their personal data can be retrieved and used inappropriately	Despeisse et al. (2017); Saidani et al. (2018); Whalen, Milios, and Nussholz (2018)

These three challenges assume a specific meaning in a CE context, since taxation and policy instruments, measures, metrics and indicators as well as standards should be shaped in a way to promote a systemic change in accordance with CE principles.

3.5. Supply chain management

The *return flows uncertainty* regarding the quantity, mix, quality, time and place of returns of products decreases the probability of achieving an economic scale in reverse logistics and renovation activities (Kumar and Putnam 2008). Currently, the greater part of products originally sold by OEMs never returns (Kalverkamp, Pehlken, and Wuest 2017). Low collection rates limit renovation activities (Ueberschaar et al. 2017), while informal collection and treatments such as illegal waste recovery further increase this uncertainty (Ranta et al. 2018). Time and place of collection are critical, too (Richter and Koppejan 2016). This challenge is well known from closed-loop supply chain literature (Winans, Kendall, and Deng 2017),

Table 8. Users' behaviour challenges.

ID	Category	Challenge	Description	Origin	Example (anecdotal)	References
22	Users' behaviour	Ownership value	Servitised BMs offer access to product instead of ownership. Consequently, users may not perceive intangible values such as self-esteem, sense of control, etc. This is particularly true in the B2C sector	Well-established challenge of servitisation	*Cars* – In e.g. a sharing system, users do not own the product. Therefore they(i.) do not have direct control on it(ii.) lose the product status-symbol	Despeisse et al. (2017); Genovese et al. (2017); Kalverkamp, Pehlken, and Wuest (2017); Lieder et al. (2018); Masi, Day, and Godsell (2017); Rizos et al. (2016); Tukker (2015)
23	Users' behaviour	Careless behaviour in product usage	Servitised BMs may lead to careless behaviour in product use and conservation by the users, since they no longer feel responsible for the product correct conservation. This may reduce the product duration, or generate legal issues between the supplier and the user	Well-established challenge of servitisation	*Machine tools*– B2B machine operator may adopt a careless usage of the machine tool provided under a leasing scheme with a full-service contract, since additional repair costs are covered by the contract	Barquet et al. (2013); Tukker (2015)
24	Users' behaviour	Users' willingness to pay	During the acquisition process, users often only consider product price as one of the main factors influencing their choice. Circular products may be characterised by high selling price, due to enhanced quality (durability) or upgradability, thus constituting a barrier for the customer. On the other side, some customer segments may not accept to buy 'second hand' (renovated or refurbished) products, due to status or fashion design reasons, or since they have a perception of lower reliability. This reduces the market size for 'renovated' products compared to new ones	It assumes a specific meaning and relevance in a CE, since users play a major role in the transition towards CE	*Washing machine* – Typically users consider washing machine price much more than usage-related costs (energy, water, etc.). Therefore, they prefer to buy cheaper models. This, in turn, brings to a higher environmental impact (cheaper models consume more energy and water during the usage phase) as well as higher total cost of ownership. On the other side, remanufactured washing machines are seen as lower quality, even though they are covered by warranty. Consequently, they are usually sent to secondary markets, at a lower price	Baxter, Aurisicchio, and Childs (2017); Bouzon, Govindan, and Rodriguez (2018); Densley Tingley, Cooper, and Cullen (2017); Geng and Doberstein (2008); Govindan et al. (2014); Govindan, Madan Shankar, and Kannan (2016); Intlekofer, Bras, and Ferguson (2010); Lewandowski (2016); Lieder et al. (2018); Masi, Day, and Godsell (2017); Mathiyazhagan et al. (2013); Nasir et al. (2017); Ongondo et al. (2013); Pitkänen et al. (2016); Ranta et al. (2018); Saidani et al. (2018); Shahbazi et al. (2016); Singh and Ordoñez (2016); van Loon and Van Wassenhove (2017); Walker, Di Sisto, and McBain (2008); Wang et al. (2016); Whalen, Milios, and Nussholz (2018); Winans, Kendall, and Deng (2017); Xue et al. (2010)

and it is critical in a CE context, since in most cases it is not possible to eliminate by design these uncertainties. Therefore the estimation of return flows of products from customers in terms of volume, mix, quality, time and place of return is challenging, thus reducing the ability to plan and execute renovation activities (Gutowski et al. 2011). Moreover, being the supply chain fragmented, actors may not be aware of the activities and planning needs of other actors. For instance, the quality of returns (state of damage, specific faults) cannot be predicted for each product unit collected at end-of-use, and timing of returns can be predicted only in the case all products are transferred to the user with contracts of known duration, which is only one among the possible options for servitised BMs contract design.

In many CE schemes, products at end-of-use have to be collected from utilisation places and sent back to specialised sites for renovation; then they are sent to where a new utilisation cycle can take place. Thus, when a supply chain is redesigned for CE, *transportation* costs and the related environmental impacts increase (Bakker et al. 2014). For instance, Krikke (2011) describes a case where, following the implementation of a closed-loop supply chain in a printing company, the amount of transportation has tripled over ten years.

The *availability of suitable supply chain partners* is another challenge widely recognised in the literature (Rauer and Kaufmann 2015). Companies who decide to move towards CE may not have access to partners with appropriate skills and the same CE commitment (Walker, Di Sisto, and McBain 2008).

Even when companies can count on a set of suitable partners, *coordination and information sharing* is difficult to achieve (Govindan et al. 2014), especially because of competition among supply chain tiers, information sensitivity, poor IT system integration or planning of activities. *Product traceability* may improve the effectiveness in planning and the efficiency in executing collection and renovation processes (Despeisse et al. 2017). However, the organisation of business processes as well as the limitations in hardware (e.g. sensors or RFID) and software (e.g. traceability systems) tools frequently do not allow storing and sharing this information effectively (Franco 2017).

Finally, internal resistance to change as well as limited awareness and commitment from both top management and employees (*cultural issues*) frequently prevent or make more difficult and troublesome the redesign of supply chain for CE (Wang et al. 2016). Even though this challenge may be caused by change as such (e.g. human inertia towards change), it is assumed that ad-hoc actions should be carried out to contrasts these cultural issues in CE contexts, so we consider this as a specific challenge of CE.

3.6. Technology

At times end-of-use processes (especially recycling) have significant environmental impact or are too expensive, thus resulting not valuable from an *eco-efficiency* perspective (Liu et al. 2017). A typical example of this challenge is provided by the WEEE recycling 'shred and separate' process, which results in materials contamination and losses (Parajuly and Wenzel 2017).

Moreover, *product technology improvement* hampers circularity: circular products, being designed to last, might not participate in the continuous technology improvement processes (Kumar and Putnam 2008). For instance, old electro-mechanical products may consume more energy than newer ones, if not properly updated (Bakker et al. 2014), thus compromising the achievement of sustainability improvements.

Finally, concerns about *data privacy and security* inhibit the adoption of supply chain redesign for CE (Saidani et al. 2018). For instance, users are reluctant to return their used smartphones, since they fear that their personal data could be retrieved and shared (Whalen, Milios, and Nussholz 2018). Given a general trend towards the manufacturing of smarter products (Porter and Heppelmann 2014), this challenge is particularly relevant. However, this also opens up great opportunities in a CE perspective. When products become smarter through the adoption of the Internet of Things (IoT) paradigm (Saidani et al. 2018), it is possible to collect huge amount of data regarding their operations. These data may in turn be used to improve e.g. the design of products as well as their maintenance (Bressanelli et al. 2018). Unfortunately, these data are not often exploited since customers are reluctant to give access to them. Such a challenge is well established in the context of information technology and digitisation. However, it acquires a specific meaning in a CE context, where these issues also concern the product end-of-use stage.

3.7. Users' behaviour

Some users may not be attracted by servitised BMs that offer product access instead of ownership (Rizos et al. 2016). This is particularly true in the B2C sector, where users may fear the loss of sense of control, availability, self-esteem or status symbol connected with *product ownership* (Tukker 2015).

Since in servitised BMs users no longer own products, a *careless behaviour in product usage* may also arise (Barquet et al. 2013), increasing repair and maintenance needs and generating relational drawbacks such as legal issues.

Table 9. Classification of the 24 challenges.

			Life cycle phase					Supply chain actor				
Category	ID	Challenge	CE specific	Raw material extraction	Production	Sales and Distribution	Utilisation	Renovation	Manufacturer	Distributor	User	Services provider
Economic and Financial viability	1	Time mismatch between revenue and cost streams			X	X	X		X	X		X
	2	Financial risk				X	X		X	X		X
	3	Operational risk				X	X		X	X		X
Market and competition	4	Cannibalisation	X			X			X	X		
	5	IP and know-how access						X	X	X	X	X
	6	Brand Image						X	X			X
Product characteristics	7	Fashion change	X				X				X	
	8	Product complexity			X			X	X			X
	9	Product (mass) customisation			X			X	X			X
Standards and regulation	10	Taxation and incentives	X	X	X	X		X	X	X	X	X
	11	Measures, metrics, indicators	X	X	X	X	X	X	X	X	X	X
	12	Lack of standards	X		X			X	X			X
Supply chain management	13	Return flows uncertainty			X			X	X		X	X
	14	Transportation and infrastructure						X	X	X		X
	15	Availability of suitable supply chain partners			X	X		X	X			X
	16	Coordination and information sharing		X	X	X	X	X	X	X	X	X
	17	Product traceability		X	X	X	X	X	X			X
	18	Cultural issue (linear mind-set)	X		X				X			
Technology	19	Eco-efficiency of technological processes						X				X
	20	Product technology improvement		X	X		X				X	
	21	Data privacy and security	X				X	X	X		X	X
Users' behaviour	22	Ownership value				X	X				X	
	23	Careless behaviour in product usage					X				X	
	24	Users' willingness to pay	X			X	X	X			X	
		Total	**8**	**5**	**12**	**11**	**12**	**15**	**18**	**9**	**11**	**17**

Moreover, *users' willingness to pay* is critical: if sold under traditional transaction-based models, the price of circular products (e.g. designed-to-last) could be higher than that of ordinary ones (Nasir et al. 2017). However, customers may not recognise a 'premium value' to them. As well, customers usually look for substantial savings when purchasing renovated or 'second-hand' products, even though they are 'as good as new' (Baxter, Aurisicchio, and Childs 2017). Nevertheless, costs for renovating processes might prevent to sell them at low price. Even though this challenge is recurrent in the remanufacturing literature, in CE this challenge assumes a specific relevance, since user involvement plays a major role (Xue et al. 2010), especially under the 'enablers' building block. In CE, customers' needs must be integrated in the business enterprise (Lieder et al. 2018).

Based on the illustration above, Table 9 summarises the identified challenges, highlighting the eight challenges that are relatively new to CE or assume a different meaning or relevance than in the past within the CE context. Moreover, it provides a further classification of the 24 challenges according to two dimensions, i.e. life cycle phase affected and supply chain actors involved. The categories considered for the supply chain actor dimension are: manufacturers (of parts, components or products), distributors (e.g. wholesalers, retailers, etc.), final users, and service providers (i.e. the subjects who provide services such as after-sales, transportation, maintenance, repair, remanufacturing, recycling, etcetera).

3.8. Levers to overcome the challenges

The analysis of the 63 papers also served to investigate the levers that companies could deploy to overcome the CE challenges.

First of all, a *modular product design* strategy should be pursued to overcome the issues arising in renovation processes due to the product complexity and product customisation challenges (Mont 2008), thanks to an easier replacement of exhausted parts and components in collected products. Products designed in a modular way also enhance product *upgradability* (Kumar and Putnam 2008; Masi, Day, and Godsell 2017), thus contrasting the challenges related to fashion change and technological evolution.

Moreover, the implementation of an '*access over ownership' revenue model* allows monetising design-to-last and maintenance efforts (Sundin and Bras 2005), thus contrasting the cannibalisation challenge. *Contractual agreements* should be put in place to define liabilities and payment schemes, and may be used to contrast both the financial and operational risks (Neely 2008). Providing in this package a set of *services that generate value to the users* is an effective lever to prevent challenges in the users' behaviour category, such as ownership value and willingness to pay (Sundin and Bras 2005).

Supply chain integration of forward and reverse activities into a single enterprise (typically the OEM) is envisaged to reduce return flows uncertainties (Rashid et al. 2013). Alternatively, the development of *partnerships* and trust among different supply chain actors has to be pursued, as a pre-condition to give access to intellectual property and know-how, enhance information sharing and mitigate other supply chain challenges (Whalen, Milios, and Nussholz 2018). Developing or exploiting specific *skills and competences* is another lever suggested by the literature, since renovation processes are often challenging due to product complexity and customisation (Lewandowski 2016).

The adoption of digital technologies such as IoT to *monitor assets state and usage conditions* mitigates challenges related to operational risks and careless behaviour in products usage (Franco 2017). As well, it improves the coordination among supply chain actors and product traceability (Bressanelli et al. 2018).

Finally, the literature suggests governmental interventions to support the adoption of CE into supply chains (Densley Tingley, Cooper, and Cullen 2017). Several attempts have been made, such as the promotion of green public procurement practices or the extended producer responsibility (Govindan, Madan Shankar, and Kannan 2016). However, this is not a kind of action whose adoption lies in the power of single companies.

Appropriate *take-back incentives,* such as the use of a deposit-refund scheme, reduce return flows uncertainties (Wojanowski, Verter, and Boyaci 2007). *Communication and awareness generation* of CE for both companies and users should come into play, to overcome cultural and willingness to pay challenges (Densley Tingley, Cooper, and Cullen 2017; Lieder et al. 2018). In this regard, eco-labelling and certifications are exemplar normative interventions to generate such awareness and willingness to pay (Masi, Day, and Godsell 2017).

4. Case studies: overcoming the Circular Economy challenges

This section presents the four cases selected (Section 2.3). All cases belong to the HA sector, where several CE initiatives are being carried out. In particular, the cases concern WMs. WMs present a great potential for CE, being suitable for servitised BMs (Tukker and Tischner 2006) and owing to the usage phase in-field more than 60% of their total cost of ownership (Saccani, Perona, and Bacchetti 2017) as well as the majority of their environmental impact (Devoldere et al. 2009). According to an Ellen MacArthur Foundation study (2012), for instance, replacing the purchase of low-end WMs with leasing of high-end ones would result in saving 180 kg of steel and more than 2.5 tons of CO_2 equivalent per household in a time frame of 20 years.

The following of this section illustrates the CE initiative undertaken by the four companies, the challenges encountered and the levers adopted to overcome them.

4.1. Company Alpha

Alpha is a startup company, founded in 2014 to offer premium WMs under a pay-per-wash or pay-per-month basis. Currently operating in a northern European country, in 2016 the company has achieved around 100 subscriptions. The company employs less than 10 employees. By subscribing to Alpha services, users can have a high-efficiency WM at home without paying its retail price, installation and repair costs. Subscriptions in fact replace the WM ownership. Each month customers pay either a fixed cost or an amount that depends on the number of washing cycles performed. Alpha offering increases material efficiency, while reducing the use of consumables such as energy, water and detergents. In fact, all the WMs offered are labelled as A + + + on the European Energy Label, and are equipped with an automatic-dosing detergent dispenser and a load detector. Among the four CE building blocks, the main one involved in the Alpha case is *servitised BMs*.

Together with the appliance, the company supplies an IoT kit to connect the WM to the Internet. The kit enables Alpha to monitor remotely the WMs. Thus, the firm provides, included in the fee, additional services such as personalised advices (e.g. how to load the WM, how to choose the most appropriate washing cycle duration or temperature, etc.), proactive maintenance and time of optimal appliance upgrade. Users who follow those tailored advices and utilise WMs in the most sustainable way may benefit from a fee reduction. Moreover, users may end the subscription each month, but the reported withdrawal rate is very limited (below 5%). In this case, the appliance is collected and a full performance check is executed: appliances are repaired, cleaned and reintroduced in a new cycle, with a new user. When appliances become less energy-efficient, they are collected and replaced. In this case, their components are used in the manufacturing of new appliances or their materials are recycled, depending on the wear and tear of the parts.

Alpha has experienced several challenges among those found in literature. First, the time mismatch between revenue and cost streams (#1) poses a financial issue to the company. However, the company counts on warranties to finance 70% of the subscriptions. Moreover, alternative financial ways, such as crowdfunding, have been pursued. To date, Alpha has raised about 500,000 dollars in crowdfunding, meaning that users believe in the company mission. Yet, through its servitised BM, Alpha is exposed to financial (#2) and operational (#3) risks. Financial risk is mitigated thanks to an initial deposit that users have to pay to start the subscription, as defined in the contractual agreement. The deposit will be returned when the subscription ends. Operational risk, instead, is mitigated by monitoring the WMs thanks to the IoT. Cannibalisation (#4) is not perceived as a challenge in the short term, given the little market share of Alpha. However, if Alpha business scales up, it could negatively affect the sales of the OEM that provides the WMs to Alpha in its traditional linear channel, since the subscription BM proposed by Alpha is in competition with the typical current sales-based business model of OEMs through retail channels. This might eventually lead to OEM to refuse to sell WMs to Alpha: this issue is not currently envisaged due to the low volumes but also to the partnership developed with the supplier of WMs. A lack of standards (#12) for the interoperability of the IoT tool provided may hinder the scalability of the business towards other appliance models. Thanks to the servitised BM adopted, and considering the limited customers' withdrawal rate, Alpha knows when most of the subscriptions will expire, thus reducing return flows uncertainties (#13). Transportation and infrastructure (#14) is not considered a challenge yet, given the relatively low number of active subscriptions and the fact that they are located in a rather small geographical area. However, it will become critical if the business scales-up. Consequently, the company is going to enforce the partnership with third-party logistic service providers, to improve WMs collection capabilities. The BM success also relies on the availability of highly efficient appliances. To this purpose, a partnership with a high-end WMs manufacturer was developed (#15). Product traceability (#17) issues are reduced thanks to the IoT kit, which allows storing a digital log of each product activity in the cloud. Consequently, aspects such as the number of washing cycles carried out or the energy consumed are traced and can be retrieved at any time, supporting effective maintenance and renovation. The product technology improvement challenge (#20) is mitigated through upgrades: since the appliance is turned into a smart product, it is possible to upgrade the software that controls the usage efficiency.

Since data are collected from households, data privacy and security (#21) concerns may arise. The company faces them by offering a full set of value-added services – mentioned above – in return for the users' consent to share data. The same policy is applied to overcome ownership value issues (#22), together with customers' communication and actions to raise awareness. A careless behaviour in product usage (#23) is discouraged by IoT monitoring and the payment of the initial deposit. Since Alpha offers highly efficient WMs, their high price may be in contrast with users' willingness to pay (#24). However, this challenge is overcome thanks to the access revenue model, through pay-per-use or monthly fixed-fee payments.

4.2. Company Beta

Beta is a distributor of spare parts for HAs, supplying customers in more than 70 countries all over the world. It offers technical assistance and spare parts to more than 2000 customers (retailers, distributors and wholesalers) all around the world. In 2016, the company had a turnover of about 15 million of euros, employing more than 20 employees. Thanks to its technical experience on components and spare parts of several brands, in 2016 the company started a project aiming to re-generate appliances that have become WEEE. This initiative has the objective of reintroducing them into a new usage cycle, instead of being disposed of, recovering (at best) materials to be recycled. Thus, Beta business re-engages WEEE and then resells them to low-income households, temporary residents as well as second homes. The project has started with one refurbishment facility, close to Beta headquarters in southern Europe. In the facility, opened in February 2017, Beta employs seven persons experienced in HA repair activities who were out of work due to the economic crisis, thus pursuing also the CE social aim. The company has recently opened a second regeneration laboratory and shop, with the double aim to sell renovated appliances and to train marginalised people in repair and remanufacturing activities.

Therefore, Beta initiative concerns the end-of-use WMs and other HA collection, renovation and re-selling activities. The company does not control the production and first-hand sales of WMs. However, Beta case is considered as a CE initiative since it contributes to sustainable development and adopts actions in at least the reverse logistics building block of CE by refurbishing, renovating and putting the appliances again in circle. In its first year of activity, the company has renovated more than 1000 WMs, with total savings on the environment of about 23 tons of concrete, 23 tons of steel, 8 tons of wire, 11 tons of bulk plastics and 3 tons of aluminium.

Beta CE project experiences several challenges. First, even though cannibalisation (#4) does not constitute a challenge in the short term, given the current low volumes of Beta business, it may become such in the long run for WM OEMs if the business scales up. More specifically, the renovated products may cannibalise the products offering of OEMs.

In turn, OEMs may hinder the company renovation activity, because of IP property and know-how (#5) issues or brand image challenge (#6). Beta faces these challenges thanks to a good collaboration with several HA brands, reinforced by its role as spare parts distributor. On the other hand, product complexity (#8) and customisation (#9) increase the difficulty in performing renovation activities. Beta mitigates these barriers by relying on the skills and competence of its workforce. When the company decided to start its re-generation activity, it faced several policy concerns (#10). For instance, it was not clear how Value Added Taxes should be paid on secondary raw materials such as WEEE. Moreover, Beta needed a qualification, issued by the local government, in order to treat WEEE. The availability of suitable partners (#15) is perceived as a great challenge by Beta, especially for what concerns the supply of WEEE to regenerate. A partnership with local smelters, who agreed to provide WEEE that are still in good conditions, reduced the impact of this challenge. Moreover, users may donate their worn-out appliances to the non-profit organisation that collaborates with Beta, as a form of user take-back incentive. These two partnerships also reduce the return flows uncertainty (#13), a challenge that is limited due to the small scale of the activities to date, but that might become relevant in the future. As in the case of Alpha, transportation and infrastructure (#14) is not considered a challenge yet, given the low volume of activity. However, it will become critical when business scales-up. In this regard, Beta has a partnership with a third-party logistics provider that delivers new appliances to end users and, at the same time, collects the old appliances (which will be renovated by Beta). The eco-efficiency of technological processes (#19) may hinder the execution of Beta activities. Product technology improvement (#20) is critical because it limits the number of appliances suitable for renovation: the company refurbishes only appliances within a high-energy efficiency label (at least A + in the European Energy Label scheme), and which are still in almost an ‘as good as new’ condition. In fact, the expected life of renovated WMs is about five years.

Finally, users’ willingness to pay (#24) has been considered as a challenge, since the company sells refurbished appliances renovated from WEEE. This challenge is faced by providing value-added services such as a one-year warranty on the WMs which includes a free technical assistance service.

4.3. Company Gamma

Gamma is a self-service laundry designer, which franchises the laundry concept, layout, equipment, detergents and support to small entrepreneurs. Gamma also directly owns some laundry facilities. Gamma is in a close partnership with a manufacturer of professional WMs, that partially owns Gamma. Recently Gamma started a project which aims to increase the share of consumers who prefer to access its washing and drying service, instead of owning personal appliances, by offering a personalised customer experience through laundry digitalisation. Laundry equipment, the automated counter and cash register where users select machines and programmes, as well as the electrical heating and security systems of the facility, are all connected to a central system. This central system allows monitoring remotely the whole facility, and the owner can remotely control the main parameters. As well, the digital solution offers the opportunity to improve customer experience through an app that provides information to users about the state of the WMs (either available or busy), so to organise their laundries, the possibility to book remotely a WM (forthcoming) and a personalisation of the customer experience based on the information about usage habits (e.g. preferred type of machines and programmes), ad hoc discounts, etcetera. The strong partnership with the OEM facilitated the technological set-up of the solution, and helped in solving technical issues related to the connection of WMs with the other equipment in the shop.

The expected outcome of such an endeavour is an extension of the WM lifecycle in the shops (through the improvement of maintenance activities), a reduction of the overall energy consumption of the facility, increased revenue streams for the self-service laundries and a reduction of the number of privately-owned WMs by household, by attracting more users that will fulfil their laundry needs only through self-service laundries.

However, Gamma faces several challenges. First, it is directly exposed to a time mismatch between revenue and cost streams (#1), financial (#2) and operational (#3) risks. The company reduces them thanks to a well-established BM and laundry concept, able to minimise the payback time to two years of activity. The availability of suitable supply chain partners challenge (#15) supplying professional WMs has been overcome thanks to the partnership with the OEM who has also a share in Gamma. Coordination and information sharing (#16) between Gamma and its franchisees is also critical. However, the digitalisation path undertaken overcomes this challenge, by means of a better communication enabled by the cloud platform system.

The product technology improvement challenge (#20) has been overcome thanks to the opportunity to upgrade washing programmes in a digital way, as in Alpha case. Following the adoption of this digital laundry project, data privacy and security concerns (#21) may arise, since a huge amount of data regarding users are gathered. However, data are not perceived as sensible by users. The ownership value loss (#22) may be mitigated through an improved customer experience (through the smartphone app, personalised alerts and discounts, etc.). Finally, the risk of careless usage behaviour (#23) may exist, but it is faced through digitalisation and monitoring of the machines at self-service laundry sites (e.g. through cameras).

4.4. Company Delta

Delta is among the world major players in the manufacturing of household appliances. The Company strategy includes the development of circular products with low environmental impact and reduced energy consumption. Thus, it has addressed design for environment to improve product performance, efficiency and serviceability, as well as to increase the share of recycled materials. In 2016, the increase in the use of recycled plastics in the manufacturing of new appliances by the company led to saving about 10,000 tonnes of virgin plastics. The company has a long-term programme to reduce plastics usage by increasing, within 2020, the volume of recycled plastic to 20,000 tonnes per year, by focusing R&D and purchasing efforts to increase the use of recycled plastic in the production of household appliances. Being an OEM, the main building block involved in the Delta case is circular product design.

In the product redesign project, aimed at both extending the lifecycle and increasing resource efficiency, Delta faces several challenges. First, circular resource-efficient products may cannibalise (#4) the existing offer of other WM models. Moreover, with a growing installed base of more ‘circular’ products with longer life in field, Delta would further reduce the number of product units sold over time, due to a lower substitution rate. However, Delta expects a higher unitary margin on the new products sales, and that new market segments will be attracted by the new offering (e.g. environmentally conscious users), thus the overall monetary effect would be positive for the company.

Fashion changes (#7) and product technology improvement (#20) are challenging in the light of the design for durability strategy adopted. These challenges are mitigated by the implementation of modular design to achieve upgradability. In this regard, upgradability allows also catching up with energy efficiency improvements, thus avoiding a net negative effect on the environment that could occur when the life of high energy-consuming products is extended. Product complexity (#8) and customisation (#9) constitute other two critical aspects, since they increase product design challenges. Again, a modular design is adopted to overcome these challenges. Taxation and incentives (#10) to the use of recyclable materials, and a higher standardisation (#12) – e.g. in secondary raw materials characteristics – are both acknowledged to be relevant challenges by Delta. Thus, lobbying activities are pursued, to incentivise policy-makers in this regard.

Usually, stakeholders assess the company performance by looking at traditional indicators such as the company turnover or market share. However, cannibalisation may reduce company primary sales. Thus, traditional indicators (#11) are inadequate to foster the CE paradigm. To overcome these issues, the company has decided to adopt additional indicators that highlight the company social and environmental awareness. Given Delta role as a manufacturing company, the linear cultural mind-set (#18) has to be overcome. In this regard, awareness generation and training activities to Delta managers may be planned by the company.

Finally, circular resource-efficient products have higher prices than traditional ones, facing the users’ willingness to pay (#24) challenge. However, since these products entail lower resource consumption during the usage phase, customers may benefit from an overall Total Cost of Ownership reduction. Therefore, this challenge may be overcome through communication and awareness generation about cost savings to customers, as well as through the adoption of pay-per-use BMs.

5. Discussion

In this section, the four cases are compared and analysed. Based on the combined analysis of the literature and the empirical findings, a conceptual framework is proposed linking the 24 challenges to a set of levers to overcome them.

Table 10 provides a cross-case comparison, summarising the challenges associated to each case.

It is worthwhile to note that all the 24 challenges have appeared at least in one case, while only one, i.e. ‘product technology improvement’, appeared in all cases. Given the different roles and activities covered by the investigated companies, which range from product design and manufacturing to end-of-use renovation, the empirical investigation confirms the distribution of CE challenges among the different lifecycle phases and supply chain actors emerged from the literature (Table 9). Consequently, the need for a systemic and holistic approach when supply chain are redesigned for CE is supported by this study (Lieder and Rashid 2016).

The findings suggest that a great degree of vertical integration by one actor in the supply chain is not a necessary condition for CE implementation, differently from findings from previous research. In fact, each case has mainly focused on one or few among the four CE building blocks, but they allow (each case alone and altogether) achieving economic, environmental and societal benefits at the aggregate level, thus contrasting previous findings that asserted the need of vertical

Table 10. Cross-case comparison: challenges pointed out in the cases.

Category	ID	Challenge	Alpha	Beta	Gamma	Delta	N° of occurrences
Economic and financial viability	1	Time mismatch between revenue and cost streams	X		X		**2**
	2	Financial risk	X		X		**2**
	3	Operational risk	X		X		**2**
Market and competition	4	Cannibalisation	X	X		X	**3**
	5	IP and know-how access		X			**1**
	6	Brand Image		X			**1**
Product characteristics	7	Fashion change				X	**1**
	8	Product complexity		X		X	**2**
	9	Product (mass) customisation		X		X	**2**
Standards and regulation	10	Taxation and incentives		X		X	**2**
	11	Measures, metrics, indicators				X	**1**
	12	Lack of standards	X			X	**2**
Supply chain management	13	Return flows uncertainty	X	X			**2**
	14	Transportation and infrastructure	X	X			**2**
	15	Availability of suitable supply chain partners	X	X	X		**3**
	16	Coordination and information sharing			X		**1**
	17	Product traceability	X				**1**
	18	Cultural issue (linear mind-set)				X	**1**
Technology	19	Eco-efficiency of technological processes		X			**1**
	20	Product technology improvement	X	X	X	X	**4**
	21	Data privacy and security	X		X		**2**
Users’ behaviour	22	Ownership value	X		X		**2**
	23	Careless behaviour in product usage	X		X		**2**
	24	Users’ willingness to pay	X	X		X	**3**
N° of challenges			**14**	**12**	**9**	**10**	

integration in order to reach CE (Rashid et al. 2013). In fact, applications limited in scope compared to the four building blocks, such as Alpha (acting only on the servitisation and digitisation building blocks), Beta (acting on the reverse logistics one) and Delta (focusing on circular product design) lay however the foundations for a more sustainable and circular HA supply chain.

Findings from the cases also allowed exploring the role and mechanisms through which companies address the challenges emerged from the literature review. In this regard, Figure 3 provides a framework that links the 24 challenges to potential levers to overcome them. The majority of levers listed in Figure 3 have already emerged from the theory (see Section 3.8) and confirmed in practice. A few ones, instead, have emerged solely from the cases or from the literature. However, a formalised matching between challenges and the levers to overcome them has been overlooked in the literature to date, despite it allows providing a greater managerial understanding of CE implications and risks.

In particular, as depicted by Figure 3:

(1) To contrast economic and financial viability challenges, contractual agreements and alternative financial solutions such as crowdfunding have emerged as levers (the latter was not found in the literature). Moreover, the adoption of IoT to enable remote asset monitoring mitigates the operational risk.

(2) Setting-up partnerships among different supply chain tiers mitigate market and competition challenges, while cannibalisation may be prevented through the adoption of an 'access' revenue model, in order to monetise the increase life duration of products generated by CE.

(3) To face challenges related to product characteristics, modular design and upgradability strategies may be pursued at the design stage. More specifically, upgradability can be reached through a modular redesign (see e.g. Delta case) or product digitisation (see, e.g. Alpha and Gamma cases). At the renovation stage, instead, the workforce skills and competence play a vital role, as shown by the Beta case.

(4) To face challenges in the domain of standards and regulations, lobbying has arisen as a possible lever to push legislation towards the implementation of adequate incentives, norms and standards. The lack of adequate metrics, instead, can be overcome through the adoption of ad-hoc sets of indicators, supported by education and training towards their use.

(5) Supply chain management challenges may be addressed through: setting close partnerships with other supply chain actors; using IoT technologies to remotely monitor assets and products; introducing take-back incentives; adopting access revenue models; and awareness generation.

		Levers	**Modular design**	**Upgradability**	**Access revenue model**	**Contractual Agreements**	**Value added services**	**Supply chain integration**	**Partnership / Collaboration**	**Skills and competence**	**Alternative financing**	**Asset remote monitoring**	**Lobbying**	**Take-back incentives**	**Communication and awareness generation**
Category	**ID**	**Challenges**													
Economic and Financial viability	1	Time mismatch between revenue and cost streams				L;C					C				
	2	Financial risk				L;C					C				
	3	Operational risk				L;C						L;C			
Market and competition	4	Cannibalisation			L										
	5	IP and know-how access							L;C						
	6	Brand Image							L;C						
Product characteristics	7	Fashion change	L,C	L,C											
	8	Product complexity	L;C							L;C					
	9	Product (mass) customisation	L;C							L;C					
Standards and regulation	10	Taxation and incentives											C		
	11	Measures, metrics, indicators											C		L,C
	12	Lack of standards											C		
Supply chain management	13	Return flows uncertainty			L;C			L	L,C					L;C	
	14	Transportation and infrastructure							L;C						
	15	Availability of suitable supply chain partners							L;C						
	16	Coordination and information sharing										L;C			
	17	Product traceability										L;C			
	18	Cultural issue (linear mind-set)													L;C
Technology	19	Eco-efficiency of technological processes													
	20	Product technology improvement		L;C											
	21	Data privacy and security					L;C								
Users' behaviour	22	Ownership value					L;C								L
	23	Careless behaviour in product usage				L;C						L;C			
	24	Users' willingness to pay			L;C		L;C								L;C

Key: 'L' means that the lever has emerged from literature; 'C' means that the lever has been found in the empirical cases

Figure 3. The framework linking CE supply chain redesign challenges with potential levers to overcome them.

(6) Technology challenges may be overcome by enhancing product upgradability or introducing value-added services in a way to reduce data privacy and security concerns.
(7) Users' behaviour challenges are addressed through value-added services and by building customer awareness, in order to increase their willingness to pay, or through asset remote monitoring and contractual agreements, to prevent careless behaviour in product usage.

As shown by the framework, some linkages (between challenges and levers) uncovered in cases have not emerged from the analysed literature. In particular, the use of alternative financial ways such as social lending and crowdfunding was not found in the extant literature, but emerged from the Alpha case as a way to contrast the time mismatch between revenue and cost streams and the financial risk challenges. This lever could be understood in the light of the recognition by the literature of a crucial role for users in CE, that even suggests to integrate customers as a part of the enterprise (Rashid et al. 2013): in this case, customer integration occurs at the financial stage. Second, even though the literature widely recognises the need for a government intervention to address standards and regulation challenges, the lobbying lever emerged through the Delta case has not been specifically investigated in CE literature yet.

Finally, the empirical investigation sheds some light on the interrelations among challenges and the implications of actions by a supply chain actor on the others. For instance, the *cannibalisation* challenge pointed out in Alpha and Beta cases does not affect the company itself, but concerns instead another actor in the supply chain – in both cases the WM OEMs, which still rely on a traditional (linear) revenue model. In addition, challenges may be less or more relevant depending on the actor that promotes the CE initiative. For instance, the *cultural issue challenge* is generally very relevant for traditional manufacturers, while is not faced by startups founded in order to develop CE approaches, such as Alpha. This evidence suggests that the severity of the challenges and their interconnections depend on the supply chain configuration and on role of the specific actor that promotes a CE initiative.

6. Conclusion

6.1. *Contribution to research*

CE is a rather new concept – though it builds on well-established disciplines such as closed-loop supply chains – which has acquired growing popularity in both scientific and popular press, entering the agendas of governments and companies. Supply chain redesign for CE requires a holistic and multidisciplinary approach, being related to CE actions on four building blocks (circular product design, servitised BMs, reverse logistics, enablers). It therefore poses several challenges. This paper contributes to the accumulation of scientific knowledge on CE with different contributions.

First, it carries out a literature review with the aim of pointing out and categorising the challenges in supply chain redesign for CE. This study contributes to filling a research gap, since a systemic and holistic view of these challenges has not been proposed in the literature to date. The analysis has led to the identification of 24 challenges, grouped into seven categories, namely: *Economic and financial viability*, *Market and competition*, *Product characteristics*, *Standards and regulation*, *Supply chain management*, *Technology*, and *Users' behaviour*.

Second, the challenges have been empirically investigated through a multiple case study in the HA supply chain and particularly concerning WM, a product category suitable for the adoption of CE principles. The categorisation obtained (see Table 9) also shows that CE challenges are quite distributed among the different lifecycle phases and supply chain actors. Therefore, the need for a systemic and holistic approach when supply chain are redesigned for CE is supported by this study. In particular, we noticed that while 16 out of 24 challenges are well known from previous research on topics such as closed-loop supply chains or servitisation, eight are relatively new to CE or take a different meaning or relevance within the CE context. These are the market c*annibalisation* (since a time dimension of cannibalisation is typical of CE, where circular products threatens future product sales), the impact of *fashion changes*, the three challenges in the standards and regulations category (*taxation and policy instruments misalignment, metrics, lack of standards), cultural issues* specific to the CE, *data privacy and security* at the end-of-use, and the *willingness to pay* for CE products.

Third, the cases also allowed exploring the mechanisms through which companies address the challenges systematised through the literature review. A set of levers that can be used to tackle these challenges has been outlined, stemming from both the literature and the empirical study. The levers have been linked to the 24 challenges in the framework presented in Figure 3, contributing to knowledge accumulation on how the CE challenges can be addressed in practice. Figure 3, besides systematising such linkages, also uncovered some (found in the case studies) that have not been thoroughly discussed in literature, in particular concerning the use of *alternative financing* (e.g. crowdfunding) to overcome economic and financial viability issues, and of *lobbying* to promote the definition of CE standards and regulations by government and institutional actors.

Finally, the four cases analysed involve actors at different supply chain levels, and have mainly focused on one or few among the four CE building blocks. This fact points to a reflection about actual CE endeavours. A thorough CE approach suggests the joint implementation of actions on the four CE building blocks discussed in this paper. In general, however, this would require a great degree of vertical integration by one actor in the supply chain, or a strong coordination and shared objectives among supply chain actors, so to govern in a harmonised way the lifecycle phases ranging from components and product development to production, distribution and sales, customer relationship during the product useful life and end-of-use activities. However, in the WM supply chains as well as in several others, even the main player (often the product OEM) has little (if any) power on other supply chain stages and on the multiplicity of players involved, as shown also by notable CE examples mentioned in Section 2.1. This, in our view, should not be taken as a limit to the application of CE principles, but should rather lead to an even more comprehensive view on the topic. CE applications such as Alpha (acting on the servitisation and digitalisation enablers) or Beta (acting instead on the reverse logistics building block), while not reaching all the objectives of CE, lead (alone and altogether) to a more sustainable development and to a more circular HA industry, bringing economic, environmental and societal benefits at the aggregate level. Therefore, we consider that all initiatives that act in one or more of the CE directions (i.e. the four building blocks) with a sustainable development aim should be considered ‘circular’ endeavours, and therefore fall into the CE definition proposed in Section 2.1.

6.2. Managerial implications

Our study contributes to providing an improved managerial understanding of CE implications and risks. Companies who wish to redesign their supply chain for CE may use the findings from this paper to anticipate likely challenges to be faced in the transition towards CE. By this token, the framework can be seen as a useful starting point for managers undertaking the path towards CE, and as a way to identify levers to overcome challenges. More specifically, the framework shows which levers may be adopted to overcome each challenge, thus giving insights to managers on how to design the path towards CE. For instance, managers should first identify the challenges that presumably the company is going to face in the CE path, and then use the framework to select the best-suited levers to overcome theme, in a way to minimise implementation costs and maximise effectiveness.

As a second contribution, the identification of levers to address the challenges supports managers in practically addressing these challenges, suggesting solutions and corrective actions against recurrent issues in CE initiatives.

6.3. Limitations and future research directions

This study has some limitations. Since the four case studies have been chosen for their appropriateness, rather than for representativeness, the external validity of the findings cannot be ensured. On account of this limitation, the findings related to the second objective (levers to address the CE challenges) can hardly be generalised (although they are discussed against a literature background) and call for an extension of the research. Exploring how levers vary across industrial sectors would allow to investigate more thoroughly the variety of potential responses to CE challenges, as well as how they vary according to factors such as industry, company size, role in the supply chain, geography, and others. This extension is, in our view, a promising avenue for future research.

Moreover, the empirical investigation shed some light on the interrelations among challenges and the implication of actions by one supply chain actor on the others, as reported in the discussion section. Future studies should focus more systematically on these interrelations – such as the implications of cannibalisation, its time dimension and the time mismatch between costs and revenue streams – and on the relationships among challenges, supply chain configuration types and CE initiative characteristics, e.g. through contingency analyses. This will further increase knowledge on CE success factors, and therefore lead to relevant managerial implications.

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References

Alghisi, Andrea, and Nicola Saccani. 2015. “Internal and External Alignment in the Servitization Journey – Overcoming the Challenges.” *Production Planning & Control* 26 (14–15): 1219–1232. doi:10.1080/09537287.2015.1033496.

Al Zaabi, Shaikha, Noura Al Dhaheri, and Ali Diabat. 2013. “Analysis of Interaction Between the Barriers for the Implementation of Sustainable Supply Chain Management.” *The International Journal of Advanced Manufacturing Technology* 68 (1–4): 895–905. doi:10.1007/s00170-013-4951-8.

ASTM. 2017. “Additive Manufacturing Technology Standards.” Accessed November 5. https://www.astm.org/Standards/additive-manufacturing-technology-standards.html#F42.05.

Baines, Tim, and Howard W. Lightfoot. 2013. “Servitization of the Manufacturing Firm.” *International Journal of Operations & Production Management* 34 (1): 2–35. doi:10.1108/IJOPM-02-2012-0086.

Bakker, Conny, Feng Wang, Jaco Huisman, and Marcel den Hollander. 2014. “Products That Go Round: Exploring Product Life Extension Through Design.” *Journal of Cleaner Production* 69: 10–16. doi:10.1016/j.jclepro.2014.01.028.

Barquet, Ana Paula Bezerra, Maicon Gouvea de Oliveira, Carolina Román Amigo, Vitor Pinheiro Cunha, and Henrique Rozenfeld. 2013. “Employing the Business Model Concept to Support the Adoption of Product–Service Systems (PSS).” *Industrial Marketing Management* 42 (5): 693–704. doi:10.1016/j.indmarman.2013.05.003.

Baxter, Weston, Marco Aurisicchio, and Peter Childs. 2017. “Contaminated Interaction: Another Barrier to Circular Material Flows.” *Journal of Industrial Ecology* 21 (3): 507–516. doi:10.1111/jiec.12612.

Bouzon, Marina, Kannan Govindan, and Carlos M. Taboada Rodriguez. 2018. “Evaluating Barriers for Reverse Logistics Implementation Under a Multiple Stakeholders’ Perspective Analysis Using Grey Decision Making Approach.” *Resources, Conservation and Recycling* 128: 315–335. doi:10.1016/j.resconrec.2016.11.022.

Braungart, Michael, William McDonough, and Andrew Bollinger. 2007. “Cradle-to-Cradle Design: Creating Healthy Emissions – A Strategy for Eco-Effective Product and System Design.” *Journal of Cleaner Production* 15 (13–14): 1337–1348. doi:10.1016/j.jclepro.2006.08.003.

Bressanelli, Gianmarco, Federico Adrodegari, Marco Perona, and Nicola Saccani. 2018. “Exploring How Usage-Focused Business Models Enable Circular Economy Through Digital Technologies.” *Sustainability* 10 (3): 639. doi:10.3390/su10030639.

Bressanelli, Gianmarco, Marco Perona, and Nicola Saccani. 2019. “Assessing the Impacts of Circular Economy: A Framework and an Application to the Washing Machine Industry.” *International Journal of Management and Decision Making* In Press: 1–27. doi:10.1504/IJMDM.2019.10015915.

Cucchiella, Federica, Idiano D’Adamo, S. C. Lenny Koh, and Paolo Rosa. 2015. “Recycling of WEEEs: An Economic Assessment of Present and Future e-Waste Streams.” *Renewable and Sustainable Energy Reviews* 51: 263–272. doi:10.1016/j.rser.2015.06.010.

Densley Tingley, Danielle, Simone Cooper, and Jonathan Cullen. 2017. “Understanding and Overcoming the Barriers to Structural Steel Reuse, a UK Perspective.” *Journal of Cleaner Production* 148: 642–652. doi:10.1016/j.jclepro.2017.02.006.

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

Devoldere, Tom, Barbara Willems, Joost R Duflou, and Wim Dewulf. 2009. “The Eco-Efficiency of Reuse Centres Critically Explored – The Washing Machine Case.” *International Journal of Sustainable Manufacturing* 1 (3): 265. doi:10.1504/IJSM.2009.023974.

Elia, Valerio, Maria Grazia Gnoni, and Fabiana Tornese. 2017. “Measuring Circular Economy Strategies Through Index Methods: A Critical Analysis.” *Journal of Cleaner Production* 142: 2741–2751. doi:10.1016/j.jclepro.2016.10.196.

Ellen MacArthur Foundation. 2012. Towards a Circular Economy – Economic and Business Rationale for an Accelerated Transition.

Ellen MacArthur Foundation. 2018. “MUD Jeans – Pioneering a Lease Model for Organic Cotton Jeans.” https://www.ellenmacarthurfoundation.org/case-studies/pioneering-a-lease-model-for-organic-cotton-jeans.

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

Geissdoerfer, Martin, Paulo Savaget, Nancy M.P. Bocken, and Erik Jan Hultink. 2017. “The Circular Economy – A New Sustainability Paradigm?” *Journal of Cleaner Production* 143: 757–768. doi:10.1016/j.jclepro.2016.12.048.

Geng, Yong, and Brent Doberstein. 2008. “Developing the Circular Economy in China: Challenges and Opportunities for Achieving ‘leapfrog Development’.” *International Journal of Sustainable Development & World Ecology* 15 (3): 231–239. doi:10.3843/SusDev.15.3:6.

Genovese, Andrea, Adolf A. Acquaye, Alejandro Figueroa, and S. C. Lenny Koh. 2017. “Sustainable Supply Chain Management and the Transition Towards a Circular Economy: Evidence and Some Applications.” *Omega* 66: 344–357. doi:10.1016/j.omega.2015.05.015.

Ghisellini, Patrizia, Catia Cialani, and Sergio Ulgiati. 2016. “A Review on Circular Economy: The Expected Transition to a Balanced Interplay of Environmental and Economic Systems.” *Journal of Cleaner Production* 114: 11–32. doi:10.1016/j.jclepro.2015.09.007.

Govindan, Kannan, Mathiyazhagan Kaliyan, Devika Kannan, and A. N. Haq. 2014. “Barriers Analysis for Green Supply Chain Management Implementation in Indian Industries Using Analytic Hierarchy Process.” *International Journal of Production Economics* 147 (PART B): 555–568. doi:10.1016/j.ijpe.2013.08.018.

Govindan, Kannan, K. Madan Shankar, and Devika Kannan. 2016. “Application of Fuzzy Analytic Network Process for Barrier Evaluation in Automotive Parts Remanufacturing Towards Cleaner Production – A Study in an Indian Scenario.” *Journal of Cleaner Production* 114: 199–213. doi:10.1016/j.jclepro.2015.06.092.

Gutowski, Timothy G., Sahil Sahni, Avid Boustani, and Stephen C. Graves. 2011. “Remanufacturing and Energy Savings.” *Environmental Science & Technology* 45 (10): 4540–4547. doi:10.1021/es102598b.

H&M Group. 2017. The H&M Group Sustainability Report 2016. H&M. https://about.hm.com/content/dam/hmgroup/groupsite/documents/masterlanguage/CSR/reports/2017%20Sustainability%20report/HM_group_SustainabilityReport_2017_FullReport.pdf

Huysman, Sofie, Jonas De Schaepmeester, Kim Ragaert, Jo Dewulf, and Steven De Meester. 2017. “Performance Indicators for a Circular Economy: A Case Study on Post-Industrial Plastic Waste.” *Resources, Conservation and Recycling* 120: 46–54. doi:10.1016/j.resconrec.2017.01.013.

Intlekofer, Koji, Bert Bras, and Mark Ferguson. 2010. “Energy Implications of Product Leasing.” *Environmental Science & Technology* 44 (12): 4409–4415. doi:10.1021/es9036836.

Kalverkamp, Matthias, Alexandra Pehlken, and Thorsten Wuest. 2017. “Cascade Use and the Management of Product Lifecycles.” *Sustainability* 9 (9): 1540. doi:10.3390/su9091540.

Kane, G. M., C. A. Bakker, and A. R. Balkenende. 2018. “Towards Design Strategies for Circular Medical Products.” *Resources, Conservation and Recycling* 135: 38–47. doi:10.1016/j.resconrec.2017.07.030.

Kazemi, Nima, Nikunja Mohan Modak, and Kannan Govindan. 2018. “A Review of Reverse Logistics and Closed Loop Supply Chain Management Studies Published in IJPR: A Bibliometric and Content Analysis.” *International Journal of Production Research*. doi:10.1080/00207543.2018.1471244.

Khodier, Ala, Karl Williams, and Neil Dallison. 2018. “Challenges Around Automotive Shredder Residue Production and Disposal.” *Waste Management* 73: 566–573. doi:10.1016/j.wasman.2017.05.008.

Kirchherr, Julian, Denise Reike, and Marko Hekkert. 2017. “Conceptualizing the Circular Economy: An Analysis of 114 Definitions.” *Resources, Conservation and Recycling* 127: 221–232. doi:10.1016/j.resconrec.2017.09.005.

Kissling, Ramon, Damian Coughlan, Colin Fitzpatrick, Heinz Boeni, Claudia Luepschen, Stefan Andrew, and John Dickenson. 2013. “Success Factors and Barriers in Re-Use of Electrical and Electronic Equipment.” *Resources, Conservation and Recycling* 80 (1): 21–31. doi:10.1016/j.resconrec.2013.07.009.

Kjaer, Louise Laumann, Daniela C. A. Pigosso, Monia Niero, Nynne Marie Bech, and Tim C. McAloone. 2018. “Product/Service-Systems for a Circular Economy: The Route to Decoupling Economic Growth From Resource Consumption?” *Journal of Industrial Ecology*. doi:10.1111/jiec.12747.

Krikke, Harold. 2011. “Impact of Closed-Loop Network Configurations on Carbon Footprints: A Case Study in Copiers.” *Resources, Conservation and Recycling* 55 (12): 1196–1205. doi:10.1016/j.resconrec.2011.07.001.

Kumar, Sameer, and Valora Putnam. 2008. “Cradle to Cradle: Reverse Logistics Strategies and Opportunities Across Three Industry Sectors.” *International Journal of Production Economics* 115 (2): 305–315. doi:10.1016/j.ijpe.2007.11.015.

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

Li, Jinhui, and Keli Yu. 2011. “A Study on Legislative and Policy Tools for Promoting the Circular Economic Model for Waste Management in China.” *Journal of Material Cycles and Waste Management* 13 (2): 103–112. doi:10.1007/s10163-011-0010-4.

Lieder, Michael, Farazee MA Asif, Amir Rashid, Aleš Mihelič, and Simon Kotnik. 2018. “A Conjoint Analysis of Circular Economy Value Propositions for Consumers: Using ‘Washing Machines in Stockholm’ as a Case Study.” *Journal of Cleaner Production* 172 (January): 264–273. doi:10.1016/j.jclepro.2017.10.147.

Lieder, Michael, and Amir Rashid. 2016. “Towards Circular Economy Implementation: A Comprehensive Review in Context of Manufacturing Industry.” *Journal of Cleaner Production* 115: 36–51. doi:10.1016/j.jclepro.2015.12.042.

Linder, Marcus, and Mats Williander. 2017. “Circular Business Model Innovation: Inherent Uncertainties.” *Business Strategy and the Environment* 26 (2): 182–196. doi:10.1002/bse.1906.

Liu, Lili, Yangyang Liang, Qingbin Song, and Jinhui Li. 2017. “A Review of Waste Prevention Through 3R Under the Concept of Circular Economy in China.” *Journal of Material Cycles and Waste Management* 19 (4): 1314–1323. doi:10.1007/s10163-017-0606-4.

Masi, Donato, Steven Day, and Janet Godsell. 2017. “Supply Chain Configurations in the Circular Economy: A Systematic Literature Review.” *Sustainability* 9 (9): 1602. doi:10.3390/su9091602.

Mathiyazhagan, K., Kannan Govindan, A. NoorulHaq, and Yong Geng. 2013. “An ISM Approach for the Barrier Analysis in Implementing Green Supply Chain Management.” *Journal of Cleaner Production* 47: 283–297. doi:10.1016/j.jclepro.2012.10.042.

Metta, Haritha, and Fazleena Badurdeen. 2013. “Integrating Sustainable Product and Supply Chain Design: Modeling Issues and Challenges.” *IEEE Transactions on Engineering Management* 60 (2): 438–446. doi:10.1109/TEM.2012.2206392.

Mont, Oksana. 2008. “Innovative Approaches to Optimising Design and Use of Durable Consumer Goods.” *International Journal of Product Development* 6 (3/4): 227. doi:10.1504/IJPD.2008.020395.

Murray, Alan, Keith Skene, and Kathryn Haynes. 2017. “The Circular Economy: An Interdisciplinary Exploration of the Concept and Application in a Global Context.” *Journal of Business Ethics* 140 (3): 369–380. doi:10.1007/s10551-015-2693-2.

Nasir, Mohammed Haneef Abdul, Andrea Genovese, Adolf A. Acquaye, S. C. L. Koh, and Fred Yamoah. 2017. “Comparing Linear and Circular Supply Chains: A Case Study From the Construction Industry.” *International Journal of Production Economics* 183: 443–457. doi:10.1016/j.ijpe.2016.06.008.

Neely, Andy. 2008. “Exploring the Financial Consequences of the Servitization of Manufacturing.” *Operations Management Research* 1 (2): 103–118. doi:10.1007/s12063-009-0015-5.

O’Connell, Maurice W., Stewart W. Hickey, and Colin Fitzpatrick. 2013. “Evaluating the Sustainability Potential of a White Goods Refurbishment Program.” *Sustainability Science* 8 (4): 529–541. doi:10.1007/s11625-012-0194-0.

Ongondo, F. O., I. D. Williams, J. Dietrich, and C. Carroll. 2013. “ICT Reuse in Socio-Economic Enterprises.” *Waste Management* 33 (12): 2600–2606. doi:10.1016/j.wasman.2013.08.020.

Parajuly, Keshav, and Henrik Wenzel. 2017. “Potential for Circular Economy in Household WEEE Management.” *Journal of Cleaner Production* 151: 272–285. doi:10.1016/j.jclepro.2017.03.045.

Park, Joo Young, and Marian R. Chertow. 2014. “Establishing and Testing the ‘Reuse Potential’ Indicator for Managing Wastes as Resources.” *Journal of Environmental Management* 137: 45–53. doi:10.1016/j.jenvman.2013.11.053.

Philips. 2015. Lighting up the National Union of Student Office. https://www.philips.com/c-dam/corporate/about-philips/sustainability/sustainable-planet/circular-economy/light-as-a-service/case-studycircular-economy-lighting-NUS.pdf

Pitkänen, K., R. Antikainen, N. Droste, E. Loiseau, L. Saikku, L. Aissani, B. Hansjürgens, P. J. Kuikman, P. Leskinen, and M. Thomsen. 2016. “What Can Be Learned From Practical Cases of Green Economy? Studies From Five European Countries.” *Journal of Cleaner Production* 139: 666–676. doi:10.1016/j.jclepro.2016.08.071.

Porter, Michael E., and James E. Heppelmann. 2014. “How Smart, Connected Product Are Transforming Competition.” *Harvard Business Review* 92 (11): 64–89.

Prosman, Ernst J., Brian V. Waehrens, and Giacomo Liotta. 2017. “Closing Global Material Loops: Initial Insights Into Firm-Level Challenges.” *Journal of Industrial Ecology* 21 (3): 641–650. doi:10.1111/jiec.12535.

Ranta, Valtteri, Leena Aarikka-Stenroos, Paavo Ritala, and Saku J. Mäkinen. 2018. “Exploring Institutional Drivers and Barriers of the Circular Economy: A Cross-Regional Comparison of China, the US, and Europe.” *Resources, Conservation and Recycling* 135: 70–82. doi:10.1016/j.resconrec.2017.08.017.

Rashid, Amir, Farazee M.A. Asif, Peter Krajnik, and Cornel Mihai Nicolescu. 2013. “Resource Conservative Manufacturing: An Essential Change in Business and Technology Paradigm for Sustainable Manufacturing.” *Journal of Cleaner Production* 57: 166–177. doi:10.1016/j.jclepro.2013.06.012.

Rauer, Johan, and Lutz Kaufmann. 2015. “Mitigating External Barriers to Implementing Green Supply Chain Management: A Grounded Theory Investigation of Green-Tech Companies’ Rare Earth Metals Supply Chains.” *Journal of Supply Chain Management* 51 (2): 65–88. doi:10.1111/jscm.12063.

Richter, Jessika Luth, and Rob Koppejan. 2016. “Extended Producer Responsibility for Lamps in Nordic Countries: Best Practices and Challenges in Closing Material Loops.” *Journal of Cleaner Production* 123: 167–179. doi:10.1016/j.jclepro.2015.06.131.

Rizos, Vasileios, Arno Behrens, Wytze van der Gaast, Erwin Hofman, Anastasia Ioannou, Terri Kafyeke, Alexandros Flamos, et al. 2016. “Implementation of Circular Economy Business Models by Small and Medium-Sized Enterprises (SMEs): Barriers and Enablers.” *Sustainability* 8 (11): 1212. doi:10.3390/su8111212.

Saccani, Nicola, Marco Perona, and Andrea Bacchetti. 2017. “The Total Cost of Ownership of Durable Consumer Goods: A Conceptual Model and an Empirical Application.” *International Journal of Production Economics* 183 (1): 1–13. doi:10.1016/j.ijpe.2016.09.021.

Saidani, Michael, Bernard Yannou, Yann Leroy, and François Cluzel. 2018. “Heavy Vehicles on the Road Towards the Circular Economy: Analysis and Comparison with the Automotive Industry.” *Resources, Conservation and Recycling* 135 (August): 108–122. doi:10.1016/j.resconrec.2017.06.017.

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

Shahbazi, Sasha, Magnus Wiktorsson, Martin Kurdve, Christina Jönsson, and Marcus Bjelkemyr. 2016. “Material Efficiency in Manufacturing: Swedish Evidence on Potential, Barriers and Strategies.” *Journal of Cleaner Production* 127: 438–450. doi:10.1016/j.jclepro.2016.03.143.

Singh, Jagdeep, and Isabel Ordoñez. 2016. “Resource Recovery From Post-Consumer Waste: Important Lessons for the Upcoming Circular Economy.” *Journal of Cleaner Production* 134: 342–353. doi:10.1016/j.jclepro.2015.12.020.

Stahel, W. R. 2013. “Policy for Material Efficiency–Sustainable Taxation as a Departure From the Throwaway Society.” *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 371 (1986): 1–17. doi:10.1098/rsta.2011.0567.

Steeneck, Daniel W., and Subhash C. Sarin. 2018. “Product Design for Leased Products Under Remanufacturing.” *International Journal of Production Economics* 202 (August). Elsevier Ltd: 132–144. doi:10.1016/j.ijpe.2018.04.025.

Sundin, Erik, and Bert Bras. 2005. “Making Functional Sales Environmentally and Economically Beneficial Through Product Remanufacturing.” *Journal of Cleaner Production* 13 (9): 913–925. doi:10.1016/j.jclepro.2004.04.006.

Tecchio, Paolo, Catriona McAlister, Fabrice Mathieux, and Fulvio Ardente. 2017. “In Search of Standards to Support Circularity in Product Policies: A Systematic Approach.” *Journal of Cleaner Production* 168. Elsevier Ltd: 1533–1546. doi:10.1016/j.jclepro.2017.05.198.

Tranfield, David, David Denyer, and Palminder Smart. 2003. “Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review.” *British Journal of Management* 14 (3): 207–222. doi:10.1111/1467-8551.00375.

Tukker, Arnold. 2015. “Product Services for a Resource-Efficient and Circular Economy – a Review.” *Journal of Cleaner Production* 97: 76–91. doi:10.1016/j.jclepro.2013.11.049.

Tukker, Arnold, and Ursula Tischner. 2006. “Product-Services as a Research Field: Past, Present and Future. Reflections From a Decade of Research.” *Journal of Cleaner Production* 14 (17): 1552–1556. doi:10.1016/j.jclepro.2006.01.022.

Ueberschaar, Maximilian, Daniel Dariusch Jalalpoor, Nathalie Korf, and Vera Susanne Rotter. 2017. “Potentials and Barriers for Tantalum Recovery From Waste Electric and Electronic Equipment.” *Journal of Industrial Ecology* 21 (3): 700–714. doi:10.1111/jiec.12577.

van Loon, Patricia, Charles Delagarde, and Luk N. Van Wassenhove. 2018. “The Role of Second-Hand Markets in Circular Business: A Simple Model for Leasing Versus Selling Consumer Products.” *International Journal of Production Research* 56 (1–2): 960–973. doi:10.1080/00207543.2017.1398429.

van Loon, Patricia, and Luk N. Van Wassenhove. 2017. “Assessing the Economic and Environmental Impact of Remanufacturing: A Decision Support Tool for OEM Suppliers.” *International Journal of Production Research* 56 (4): 1662–1674. doi:10.1080/00207543.2017.1367107.

Voss, Chris, Nikos Tsikriktsis, and Mark Frohlich. 2002. “Case Research in Operations Management.” *International Journal of Operations & Production Management* 22 (2): 195–219. doi:10.1108/01443570210414329.

Wakolbinger, Tina, Fuminori Toyasaki, Thomas Nowak, and Anna Nagurney. 2014. “When and for Whom Would E-Waste Be a Treasure Trove? Insights From a Network Equilibrium Model of e-Waste Flows.” *International Journal of Production Economics* 154: 263–273. doi:10.1016/j.ijpe.2014.04.025.

Walker, Helen, Lucio Di Sisto, and Darian McBain. 2008. “Drivers and Barriers to Environmental Supply Chain Management Practices: Lessons From the Public and Private Sectors.” *Journal of Purchasing and Supply Management* 14 (1): 69–85. doi:10.1016/j.pursup.2008.01.007.

Wang, Zhigang, K. Mathiyazhagan, Lei Xu, and Ali Diabat. 2016. “A Decision Making Trial and Evaluation Laboratory Approach to Analyze the Barriers to Green Supply Chain Management Adoption in a Food Packaging Company.” *Journal of Cleaner Production* 117: 19–28. doi:10.1016/j.jclepro.2015.09.142.

Whalen, Katherine A, Leonidas Milios, and Julia Nussholz. 2018. “Bridging the Gap: Barriers and Potential for Scaling Reuse Practices in the Swedish ICT Sector.” *Resources, Conservation and Recycling* 135: 123–131. doi:10.1016/j.resconrec.2017.07.029.

Winans, K., A. Kendall, and H. Deng. 2017. “The History and Current Applications of the Circular Economy Concept.” *Renewable and Sustainable Energy Reviews* 68: 825–833. doi:10.1016/j.rser.2016.09.123.

Wojanowski, Rico, Vedat Verter, and Tamer Boyaci. 2007. “Retail–collection Network Design Under Deposit–refund.” *Computers & Operations Research* 34 (2): 324–345. doi:10.1016/j.cor.2005.03.003.

Wübbeke, Jost, and Timo Heroth. 2014. “Challenges and Political Solutions for Steel Recycling in China.” *Resources, Conservation and Recycling* 87: 1–7. doi:10.1016/j.resconrec.2014.03.004.

Xue, Bing, Xing-peng Chen, Yong Geng, Xiao-jia Guo, Cheng-peng Lu, Zi-long Zhang, and Chen-yu Lu. 2010. “Survey of Officials’ Awareness on Circular Economy Development in China: Based on Municipal and County Level.” *Resources, Conservation and Recycling* 54 (12): 1296–1302. doi:10.1016/j.resconrec.2010.05.010.

Yin, Robert K. 2009. *Case Study Research: Design and Methods. Case Study Research Design and Methods*. 4th ed. Thousand Oaks, CA: Sage Publications.

Appendix. Research protocol and track interview.

The following research protocol was established, to facilitate the qualitative data collection during interviews. Not to disclose confidential information, a simplified version is here provided.

Phase	Guidelines for interview and instructions
0. Presentation and introduction of the theme	**Presentation** Good morning, my name is . . . and I am a researcher at . . . We wish to thank you for agreeing to undertake the interview. **Aim** The aim of this interview is to get a comprehensive overview of the challenges that arise when a supply chain is redesigned for CE. Moreover, we want to shed light on the levers. **Support material** I shared with you (approximately a couple of weeks ago) some supporting documentation, including the research background, a glossary of terms and a list of challenges that emerged through a systematic screening of the scientific literature (cf. Tables 2–8). I hope you have had time to read it. **General Instruction** Please be aware that there is no right or wrong answer, but we wish you answer based on your best knowledge. While I focus on asking questions, my colleague will take care of taking notes. **Confidentiality** No information about the company name will be revealed. The interview willbe transcribed, so to extract the most relevant parts from your valuable feedback. Data will be treated in a confidential way.
1. General questions about the company	First, we would like to ask you some general questions about your company. Could you please describe: (i.) who you are and what is your role in the company; (ii.) the main activities of your company and its supply chain structure; (iii.) the evolution of the company turnover over years; (iv.) the size of the company (i.e. the number of employees); (v.) the CE project undertaken by your company; (vi.) the scope of the CE project; (vii.) the motivation behind the decision to undertake such a project.
2. Targeted questions about the CE projects undertaken	Now we have some targeted questions regarding the CE project undertaken. First, could you please describe whether and how the four CE building blocks (circular product design, servitised BMs, reverse logistics and enablers) have been implemented by the company?*For confidential reasons, the remaining content of this section is here omitted.*
3. Specific questions about CE challenges	Now we would like to discuss the challenges faced in your CE project. *For each of the 24 challenges:* • Is your company facing the challenge number X? (If the challenge is not clear to the interviewee, use an anecdotal example as in Tables 2–8) • If yes, in which situation? Did this challenge specifically emerged in a CE context or it has emerged in other contexts too? In which life cycle phase (or phases) did it emerge? Which supply chain actors have been touched by this challenge? • If your company is facing this challenge, how is your company trying to overcome it? After having discussed the 24 challenges, could you please tell me which ones were the most relevant in your opinion (*up to three*)? Are there any challenges you faced that are not included in the list? If so, could you please describe them?
4. Levers investigation	Based on our discussion so far, we have extracted a list of levers that your company has used (or is using) in order to address one or more challenges. Could you please confirm if this list is pertinent to your CE project? *(list the levers emerged from the interview so far)* Are there any other levers you adopted that are not included in the list? If so, could you please describe them in few words?
5. Conclusion	Thanks again for your time. We will send back our notes for further validation. Results from your case are going to be systematised and finalised (although in an anonymous way). We will be glad to share the final report with you.