Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 73 (2018) 216–221

www.elsevier.com/locate/procedia

10th CIRP Conference on Industrial Product-Service Systems, IPS^2 2018, 29-31 May 2018, Linköping, Sweden

The role of digital technologies to overcome Circular Economy challenges in PSS Business Models: an exploratory case study

Gianmarco Bressanelli[a,*], Federico Adrodegari[a], Marco Perona[a], Nicola Saccani[a]

[a]*RISE Laboratory, University of Brescia, Via Branze 38, Brescia 25123, Italy*

* Corresponding author. Tel.: +39 030 3715760. *E-mail address:* g.bressanelli002@unibs.it

Abstract

Circular Economy has been usually indicated as a promising approach to promote economic development and sustainability. Despite this general agreement, the Circular Economy paradigm is still little adopted by companies, as they need to face several challenges. In this context, Product-Service Systems (PSS) Business Models play a major role, as they have been proposed as an opportunity for promoting sustainability. Today, digital technologies are seen as a key factor to enable PSS, allowing at the same time the introduction of Circular Economy into companies. However, little attention has been set on how new digital technologies can overcome in practice the main Circular Economy challenges. To fill this gap, this paper explores such a role through a case study of a company who leverages Internet of Things, Big Data and Analytics in the provision of its PSS Business Model. Based on the findings of the empirical investigation, the role that the selected digital technologies play in overcoming the Circular Economy challenges is presented and discussed.

Peer-review under responsibility of the scientific committee of the 10th CIRP Conference on Industrial Product-Service Systems.

Keywords: Circular Economy; PSS; Business Model; Digital technology; Industry 4.0.

1. Introduction

The concept of Circular Economy (CE) has reached increasing attention among academia and practitioners as a mean to promote sustainability [1], since it aims to decouple economic growth from resource extraction and environmental losses [2]. Indeed, recent studies advocate that the application of the CE principles may increase the European GDP of about 11%, bringing to a net benefits of about € 1.8 trillion by 2030 without compromising the environment [2].

In this context, Product-Service Systems (PSS) business models (BMs), in which the function or the utilization of a product is sold instead of the product itself, have been recognised as one possible enabling factor of the CE paradigm into companies [2–4]. Moreover, many works recognise fast evolving digital technologies as an enabler factor of novel product-service offerings [5]. Consequently, digital technologies highlighted by the fourth industrial revolution (Industry 4.0) such as Internet of Things (IoT), 3D printing, Big Data and Analytics enhance the introduction of CE into companies [6–9].

However, the transition towards CE and PSS BMs implies major challenges for companies [10–12]. Despite this general agreement, little attention has been paid to how digital technologies may be used to overcome CE challenges [13].

To fill this gap, this paper aims to explore how digital technologies like IoT, Big Data and Analytics may be used to overcome the CE challenges that arise when companies adopt a PSS BM, by the means of a case study.

Therefore, the paper is organised as follows. Section 2 describes the background of the study, focusing on CE and PSS BMs, on the challenges that arise when PSS BMs are adopted to reach CE and on the role of the selected digital technologies (i.e. IoT, Big Data and Analytics) in advancing CE. Then, Section 3 highlights the method applied, while Section 4 presents the results of the case study. In Section 5, a discussion of the results is provided. Lastly, conclusions, limitations and future research avenues are highlighted in Section 6.

2212-8271 © 2018 The Authors. Published by Elsevier B.V.
Peer-review under responsibility of the scientific committee of the 10th CIRP Conference on Industrial Product-Service Systems.
10.1016/j.procir.2018.03.322

2. Background

2.1. Circular Economy and PSS Business Models

Notwithstanding the body of knowledge regarding CE is still in its infancy [7], the concept has its roots in other school of thoughts such as industrial ecology, cradle-to-cradle, blue economy and biomimicry [14–16]. However, a detailed definition of CE is still missing in the literature [17]. In this paper, the definition of CE coded by Kirchherr et al. [17] is adopted. They define CE as 'an economic system that is based on business models which replace the end-of-life concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes […] with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations' [17]. To this regard, CE contrasts the linear economy, i.e. the traditional economic system where products are manufactured from raw materials, sold to consumers and then disposed as waste after use, by enhancing multiple closed-loop cycle of reuse, remanufacturing and recycling [18]. Thus, CE gives an equal attention to both the forward and the reverse flows of materials, components and products, thanks to the implementation of reverse logistics and closed-loop supply chain [19]. Products should be then redesigned with the aim to improve multiple lifecycles, thus improving product reuse, refurbishment, remanufacturing and recycling. In this regard, several design-for-x strategies such as eco-design [20], product life extension [21], modularisation, standardisation and material selection [13] may be pursued.

The Kirchherr et al.'s definition of CE [17] gives a great emphasis on the notion of BM. Literature agrees that shifting from traditional sales-oriented BMs to servitised ones can incentivise companies in moving towards CE [2,4]. Moreover, adopting PSS, i.e. integrated bundles of products and services aiming to create customer value [22], represent an excellent vehicle to foster sustainability [23]. The opportunities for improvement with regard to sustainability differ significantly depending on the type of PSS used. Tukker [23] proposes three different categories of PSS, namely product-oriented, use-oriented and result-oriented.

In product-oriented BMs, the purpose is to deliver tangible value to the customer [23]. The product ownership is transferred to the customer, while the company can sell a combination of single standard products and industrial services, such as maintenance and repair. Moreover, the company has no responsibility for product lifecycle and the main revenue stream is represented by product sales [24].

In use-oriented BMs, the customer does not buy the product but instead pays a fee to gain access to it [23,25]. Thus, the company takes responsibility for providing lifecycle services such as maintenance, repair and control. Furthermore, the company is incentivised to design products in terms of which elements can be reused after their first life [24]. Thus, the product should be easy to maintain, reuse, upgrade [26].

In result-oriented BMs, customers do not buy the product but pay a variable fee that depends on its actual usage or on the achievement of a result or outcome [23]. Therefore, the value is generated by an individualised and integrated combination of products and services to produce the expected results [27]. Thus, revenues are generally based on outcome units that are paid for the result [25]. In accordance with Tukker [4], result-oriented BMs may be the most effective to move towards CE.

2.2. Circular Economy challenges

When companies adopt a PSS BM aiming to reach CE, several challenges arise. First, when products are offered through PSS BMs, *financial risks* are transferred from users to providers [3,12]. More specifically, providers are financially exposed to the risk of an early suspension of the contract by customers, even though they have financed in advance the entire solution. Moreover, a time mismatch between revenue and cost streams arises, since providers who convert their offering to a PSS provision over time have to finance in advance the capital costs of the solution [4,27], while revenue streams are postponed over time [11].

Furthermore, also *operational risks* are transferred to providers [28]. In a PSS BM, users no longer own products, and a careless behaviour in product usage may arise [4,27], increasing repair and maintenance activities and costs, which are in charge of the providers.

Some users may not be attracted by PSS BMs that offer product access instead of ownership [11]: the *loss of ownership* may bring a loss of the sense of control, availability, self-esteem or status symbol connected with the product ownership [4]. Moreover, users' *willingness to pay* becomes critical: customers usually look for substantial savings when accessing renovated or 'second-hand' products, even though they are 'as good as new' [29]. Nevertheless, costs for renovating processes might prevent to offer them at such a lower fee.

In general, companies may avoid to provide remanufactured products under a PSS BM because they fear that this offering may lead to a reduction of primary sales [20]. This phenomenon, also called market *cannibalisation* [12], is critical especially when PSS access offerings have lower profit margin than cannibalised ones [30].

Since products in a CE are designed to last, rather than for use-and-throw-away, they might be unable to respond to *technology improvement*, resulting unattractive for a part of the customer base [4,12,15]. For instance, old electro-mechanical products may consume more energy than newer ones [21], thus compromising the achievement of sustainability improvements.

Finally, CE pushes companies to adopt BMs where end-of-life is replaced with renovation [17]. Thus, *return flows uncertainties* regarding the quantity, the mix, the quality, the time and the place of returns of products offered through a PSS BM decrease the probability of achieving an economic scale in reverse logistics and renovation activities [15,31].

2.3. Internet of Things, Big Data and Analytics for the Circular Economy

Literature acknowledges IoT, Big Data and Analytics as enablers for the transition towards PSS BMs [32] and CE [2,7]. While the enabling role of digital technologies for the servitization of companies has been thoroughly investigated by previous studies (see, for instance, the work of Ardolino et al. [33]), their specific role for CE has been quite under-investigated to date [13].

The Internet of Things (IoT) technology refers to supplying devices with sensors, which give them the ability to communicate and to become active participants in an information network [32]. To this regard, Porter and Heppelmann [34] showed how the application of the IoT technology turns stand-alone products into smart and connected ones, pointing out the functionalities of monitoring product status and condition. Therefore, thanks to the IoT, companies may obtain real-time remote monitoring of product usage, status, and location [35], thus having the great opportunity to gain knowledge on how customers are using products. When products become smart, companies may upgrade only their digital components, such as the product firmware. Therefore, product upgradability is enhanced [32], which in turn contrasts product obsolescence and its resulting material waste, helping the transition towards CE [36]. Finally, Cheng, Barton, and Prabhu [37] have pointed out the crucial role of sensors like radio frequency identification (RFID) in tracing spare parts. Consequently, the IoT technology may also support material tracking [3], contributing to the collection of end-of-life products [8].

The IoT technology allows companies to collect a large amount of data [13], usually called Big Data. Given their volume, variety, velocity and veracity [7], Big Data cannot be analysed using traditional software or database techniques, but require specific Analytics to leverage software and data mining processes, in order to identify patterns in the data and make predictions [8]. Thus, Big Data combined with appropriate Analytics are usually seen in literature as a valid approach to enable a better decision making [8], which can positively advance management towards CE by feeding sustainability-oriented decision-making processes with the required information [7]. Furthermore, Big Data and Analytics are required in the provision of advanced services such as preventive and predictive maintenance [35].

3. Research gap, design and method

Despite the relevant role that digital technologies play in the transition towards CE, little attention has been set from literature on how their application may be used to overcome the challenges that arise when companies adopt a PSS BM.

Starting from this gap, the paper aims to explore how IoT, Big Data and Analytics may be used to overcome the CE challenges emerged from literature. Given the exploratory purpose of this research, as well as the fact that the body of CE knowledge is in its infancy [7], a case study was considered as the suited methodology for the empirical investigation of this paper [38]. In fact, case study methodology is invaluable for exploring the detailed working of an organisation [35], and qualitative case studies are needed for the initial stage of investigation [7]. Consequently, a company was selected, following two main criteria. First, the company should have leveraged IoT, Big Data and Analytics for the provision of its offering. Second, the company should have adopted a PSS Business Model that replaces the end-of-life concept with reducing, reusing, recycling and recovering materials in production/distribution and consumption processes, as stated by the CE definition. Furthermore, it was decided to select a company operating in a sector particularly promising for the adoption of the CE paradigm. In this regard, the household appliances sector was selected [20]. In fact, previous studies have shown that, in the case of a CE scenario for washing machines, customers could benefit from an average yearly saving of almost 30% of the current washing cost, while environment could benefit from a total reduction of electricity generation and water consumption of about 0.6% and 1% respectively [9].

Thus, one company who retails household appliances has been contacted and accepted to participate in the study. To protect its business interest, the company identity has been here concealed. A research protocol was utilised in order to enhance reliability and validity of case research, encompassing case study design, data collection, data analysis and results formalisation. More specifically, data collection was performed through different methods, ranging from a preliminary questionnaire to gather general information about the company and the context in which it operates (its turnover, the number of employees, and so forth) to semi-structured interviews to gather other specific data related to the company BM, the digital technologies adopted and the challenges faced. Three interviews were performed, respectively to the company CEO and to the SW development manager. Each interview lasted between one and two hours, and more than one researcher participated simultaneously, in order to enhance the study reliability. Each interview was transcribed and coded, and the text was eventually sent back to respondents for clarification and validations. To enhance construct validity, all the gathered information was triangulated with secondary sources, such as the company website and other company documentations [38]. Then, the last phase of the research protocol was conducted, looking for explanations of the coded sequence of events, thus trying to bridge the gap found in literature.

4. The case study

4.1. Company PSS Business Model

Alpha is a household appliance retailer who operates prevalently in a Northern-Europe Country. Founded in 2014, it provides large household appliances such as washing machines, dishwashers and tumble dryers, adopting a PSS BM. In fact, instead of physically sells appliances to households, the company offers to their customers the opportunity to subscribe contracts (i.e. subscriptions) that give them the right of access to the appliance performance. Thus, the company retains the ownership of appliances, and customers become users. In 2016, Alpha has achieved more than 1,000 subscriptions, which generate a turnover of about 0.5 million €. The company dimension is relatively small, since it employs less than 10 employees.

Through the subscription offered, users may access a high-efficient appliance directly at their home, without having to pay for its initial price, which is typically high since it justifies the high quality and efficiency of the appliance offered. For instance, all the washing machines offered through the company's subscriptions are classified as A+++ on the European Energy Label, and are equipped with a load detector and an automatic-dosing detergent dispenser. Instead of paying an initial price, users pay each month an amount that depends on the real appliance usage. Thus, the company offers household appliances under a pay-per-use scheme, which may be classified as a use-oriented BM [23]. Moreover, the appliances transportation and installation costs are included in the monthly fee. Users who decide to start a subscription pay an initial deposit as a warranty. Thanks to this kind of warranties, the company is able to finance up to the 70% of the subscriptions. This deposit will be returned when the subscription ends. Each month, users may decide to stop the subscription. When users shut down the subscription, the appliance is collected by the company. A full performance check is executed and, after that, Alpha provides it to a new user, within a new subscription. When appliances become technologically obsolete, they are collected and replaced: old appliances are repaired, refurbished, cleaned and, when becoming energy inefficient, their components are extracted and used in the manufacturing of new appliances, or recycled.

Even though the assessment of the environmental and economic impact of a PSS solution requires an in-depth analysis (see for instance [39]), it can be observed that Alpha achieves circularity through its PSS BM thanks to several reasons. First, each subscription replaces the ownership of low-efficient appliances with high-efficient ones, thus reducing the use of consumables such as energy, water and detergents and therefore increasing resources efficiency. Second, the company replace the end-of-life concept – according to the CE definition – with multiple cycles, since each appliance is collected and renovated when the subscription ends.

4.2. Digital technologies to overcome Circular Economy challenges

To deliver its PSS BM, the company supplies to households an IoT kit developed in house which connects appliances to the internet through a plug-and-bridge instrument. Thus, the kit transforms usually stand-alone appliances into smart and connected products [34], enabling the appliance monitoring and control during its usage as well as the collection of large amount of Big Data, which are properly analysed through Analytics. Thanks to the utilization of these digital technologies, Alpha overcomes several challenges among those found in literature (see Section 2.2).

In particular, operational risks usually generated by careless behaviour in products usage are mitigated thanks to the monitoring of users' activities through the IoT, which allows storing a digital log of each product activity in the cloud. Since users are constantly monitored, their opportunistic behaviour is prevented.

Since in the case of Alpha users do no longer own appliances, 'loss of ownership' issues may arise. The company faces them by offering advanced services, which generate value for customers, such as the optimization of the usage phase and the provision of preventive and predictive maintenance, both included in the subscription fee. In fact, thanks to the analysis of Big Data collected through the IoT tool, Alpha discloses to customers personalised advices such as, in the case of washing machine subscription, the better washing cycle duration or the better washing temperature to reduce energy and water consumption. More specifically, a mobile App provides hints to use fewer detergents and to conserve water and energy, starting from the IoT monitoring of the electricity, water and detergent consumption, the washing load, the number of cycles, etcetera. Users are therefore incentivised to reduce their washing environmental impact, because who decides to follow these tailored advices is awarded by a reduction of its monthly fee. Moreover, by retrieving the data collected through the IoT kit and by analyzing these (Big) Data through appropriate Analytics, Alpha is able to define the expected lifetime of components. This information is utilised for feeding the preventive and predictive maintenance algorithms offered by the company to its users.

The technology improvement challenge is mitigated through digital upgrades: since the appliance is turned into a smart and connected product [34], it becomes possible to upgrade just its digital part, i.e. the software that controls the usage of consumables by households, thus incorporating the most up-to-date programs and therefore pursuing resource efficiency. This allows achieving a reduction of consumables and an extension of the product lifespan: old appliances may stay operative for a longer time, since they remain competitive.

Finally, since aspects such as the number of washing cycles carried out or the components physical status are monitored, known at any time and analysed, Alpha can predict when most of the appliances should be replaced. Thus, return flow uncertainties are reduced, and the organisation of collection activities is enhanced.

Challenges related to financial risks and cannibalisation are faced by Alpha, but digital technologies do not help to overcome them. Findings are summarised in Table 1.

5. Discussion

The Alpha case shows how digital technologies may be used to overcome the CE challenges emerged from literature. More specifically, the case indicates that, following the adoption of IoT, Big Data and Analytics, a company is able to offer a set of functionalities that, in turn, helps to overcome such challenges. In particular, the IoT technology enables the monitoring of users' activities [7,13,35], thus discouraging careless behaviour and reducing operational risks. Thanks to the IoT tool, companies know appliances status and location. Therefore, this information is used when each product reaches the end-of-life, to enhance the organization of collection activities [8,35]. Moreover, making product connected through IoT entails an easier product upgrade, thus preventing the technology improvement challenge. When IoT is combined with Big Data and Analytics techniques, the case shows that also the challenges related to the loss of ownership, the willingness to pay and the return flows uncertainties are overcome. In particular, the provision of advanced services such as preventive and predictive maintenance [32,34,35] or the optimization of the usage phase [34,25] represents a way to persuade customer to leave the ownership of products to the company. On the other hand, the estimation of components and products expected life (driven by the analysis of Big Data through Analytics) reduces the return flows uncertainties.

Table 1. How IoT, Big Data and Analytics help to overcome Circular Economy challenges in the Alpha case

Circular Economy challenges	How the challenge is overcome (i.e. through which functionality)	Digital Technologies	
		IoT	Big Data & Analytics
Financial risks	N.a.	N.a.	N.a.
Operational risks	Monitoring users' activities	X	
Loss of ownership	Advanced services such as the optimization of the usage phase or the provision of preventive and predictive maintenance	X	X
Willingness to pay	Advanced services such as the optimization of the usage phase or the provision of preventive and predictive maintenance	X	X
Cannibalisation	N.a.	N.a.	N.a.
Technology improvement	Digital upgrade	X	
Return flow uncertainties	Product tracking and estimation of products and components residual life	X	X

Key: 'N.a.' means that, even though the challenge is faced by Alpha, the digital technologies investigated do not help to overcome it.

As shown by Table 1, only two of the seven challenges identified in literature are not overcome through the adoption of digital technologies. These challenges are financial risks and cannibalisation. However, since five out of seven challenges are prevented by the functionalities enabled through IoT, Big Data, and Analytics, it can be stated that the contribution of these selected technologies is not negligible in the transition towards CE. Nevertheless, a detailed investment analysis should not be avoided before investing in these technologies. Finally, even though IoT, Big Data and Analytics play a relevant role in overcoming a not negligible number of challenges, it may be noted that their adoption brings other remarkable concerns. A notable example is the new challenge that arises when products become smart, i.e. the challenge related to privacy and data security [6]. In this case, customers are reluctant to share with the provider the data that are required to perform preventive maintenance or the optimization of the usage phase, thus compromising their provision.

6. Conclusion

Literature recognises PSS BMs and digital technologies as enablers for the transition towards CE [6–8]. However, this implies major challenges for companies [10–12]. Despite this general agreement, little attention has been devoted on how digital technologies may be used to overcome CE challenges. This paper has tried to fill this gap by the means of a single case study. More specifically, this research asserts that the digital technologies investigated, i.e. IoT, Big Data and Analytics, allow the company to overcome CE challenges like operational risks, loss of ownership, users' willingness to pay, technology improvement and return flow uncertainties. These challenges are overcome by the means of four digitally-enabled functionalities: (i.) monitoring users' activities, (ii.) the provision of advanced services such as preventive and predictive maintenance or the optimization of the usage phase, (iii.) digital upgrade and (iv.) estimation of products and components residual life.

This paper adds to current research since it highlights the fact that only two of the seven challenges identified in literature are not overcome through the adoption of digital technologies. Therefore, the contribution of IoT, Big Data and Analytics is relevant in overcoming the CE challenges, even though a detailed investment analysis should not be avoided before investing in these technologies. Managers may use the results of this study in order to design a CE transition path, by purposively choosing which digital technologies implement (either IoT or the bundle IoT, Big Data and Analytics), depending on the challenges that presumably are going to be faced.

However, this paper has some limitations. Generalization is difficult to achieve since only one case study has been performed. Moreover, not all the digital technologies highlighted by Industry 4.0 have been explored in this study. Finally, a detailed assessment of the economic and environmental impacts of the Alpha BM should be conducted, e.g. following the work of Lindahl et al. [39]. These limitations provide suggestions for future research directions.

References

[1] Ghisellini P, Cialani C, Ulgiati S. A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. J Clean Prod 2016;114:11–32. doi:10.1016/j.jclepro.2015.09.007.

[2] Ellen MacArthur Foundation. Intelligent Assets: Unlocking the Circular Economy Potential. Ellen MacArthur Found 2016.

[3] Lewandowski M. Designing the Business Models for Circular Economy—Towards the Conceptual Framework. Sustainability 2016;8:43. doi:10.3390/su8010043.

[4] Tukker A. Product services for a resource-efficient and circular economy – a review. J Clean Prod 2015;97:76–91. doi:10.1016/j.jclepro.2013.11.049.

[5] Adrodegari F, Saccani N. Business models for the service transformation of industrial firms. Serv Ind J 2017;37:57–83.

doi:10.1080/02642069.2017.1289514.

[6] Despeisse M, Baumers M, Brown P, Charnley F, Ford SJ, Garmulewicz A, et al. Unlocking value for a circular economy through 3D printing: A research agenda. Technol Forecast Soc Change 2017;115:75–84. doi:10.1016/j.techfore.2016.09.021.

[7] Jabbour CJC, Jabbour ABL de S, Sarkis J, Filho MG. Unlocking the circular economy through new business models based on large-scale data: An integrative framework and research agenda. Technol Forecast Soc Change 2017. doi:10.1016/j.techfore.2017.09.010.

[8] Pagoropoulos A, Pigosso DCA, McAloone TC. The Emergent Role of Digital Technologies in the Circular Economy: A Review. Procedia CIRP, vol. 64, 2017, p. 19–24. doi:10.1016/j.procir.2017.02.047.

[9] Bressanelli G, Perona M, Saccani N. Reshaping the Washing Machine Industry through Circular Economy and Product-Service System Business Models. Procedia CIRP 2017;64:43–8. doi:10.1016/j.procir.2017.03.065.

[10] Alghisi A, Saccani N. Internal and external alignment in the servitization journey – overcoming the challenges. Prod Plan Control 2015. doi:10.1080/09537287.2015.1033496.

[11] Rizos V, Behrens A, van der Gaast W, Hofman E, Ioannou A, Kafyeke T, et al. Implementation of Circular Economy Business Models by Small and Medium-Sized Enterprises (SMEs): Barriers and Enablers. Sustainability 2016;8:1212. doi:10.3390/su8111212.

[12] Linder M, Williander M. Circular Business Model Innovation: Inherent Uncertainties. Bus Strateg Environ 2017;26:182–96. doi:10.1002/bse.1906.

[13] Nobre GC, Tavares E. Scientific literature analysis on big data and internet of things applications on circular economy: a bibliometric study. Scientometrics 2017;111:463–92. doi:10.1007/s11192-017-2281-6.

[14] Geissdoerfer M, Savaget P, Bocken NMP, Hultink EJ. The Circular Economy – A new sustainability paradigm? J Clean Prod 2017;143:757–68. doi:10.1016/j.jclepro.2016.12.048.

[15] Franco MA. Circular economy at the micro level: A dynamic view of incumbents' struggles and challenges in the textile industry. J Clean Prod 2017;168:833–45. doi:10.1016/j.jclepro.2017.09.056.

[16] Lieder M, Rashid A. Towards circular economy implementation: a comprehensive review in context of manufacturing industry. J Clean Prod 2016;115:36–51. doi:10.1016/j.jclepro.2015.12.042.

[17] Kirchherr J, Reike D, Hekkert M. Conceptualizing the circular economy: An analysis of 114 definitions. Resour Conserv Recycl 2017;127:221–32. doi:10.1016/j.resconrec.2017.09.005.

[18] Braungart M, McDonough W, Bollinger A. Cradle-to-cradle design: creating healthy emissions – a strategy for eco-effective product and system design. J Clean Prod 2007;15:1337–48. doi:10.1016/j.jclepro.2006.08.003.

[19] Kumar S, Putnam V. Cradle to cradle: Reverse logistics strategies and opportunities across three industry sectors. Int J Prod Econ 2008;115:305–15. doi:10.1016/j.ijpe.2007.11.015.

[20] Mont O. Innovative approaches to optimising design and use of durable consumer goods. Int J Prod Dev 2008;6:227. doi:10.1504/IJPD.2008.020395.

[21] Bakker C, Wang F, Huisman J, den Hollander M. Products that go round: exploring product life extension through design. J Clean Prod 2014;69:10–6. doi:10.1016/j.jclepro.2014.01.028.

[22] Boehm M, Thomas O. Looking beyond the rim of one's teacup: a multidisciplinary literature review of Product-Service Systems in Information Systems, Business Management, and Engineering & Design. J Clean Prod 2013;51:245–60. doi:10.1016/j.jclepro.2013.01.019.

[23] Tukker A. Eight types of product–service system: eight ways to sustainability? Experiences from SusProNet. Bus Strateg Environ 2004;13:246–60. doi:10.1002/bse.414.

[24] Adrodegari F, Saccani N, Kowalkowski C, Vilo J. PSS business model conceptualization and application. Prod Plan Control 2017;28:1251–63. doi:10.1080/09537287.2017.1363924.

[25] Reim W, Parida V, Örtqvist D. Product–Service Systems (PSS) business models and tactics – a systematic literature review. J Clean Prod 2015;97:61–75. doi:10.1016/j.jclepro.2014.07.003.

[26] Bocken NMP, de Pauw I, Bakker C, van der Grinten B. Product design and business model strategies for a circular economy. J Ind Prod Eng 2016;33:308–20. doi:10.1080/21681015.2016.1172124.

[27] Barquet APB, de Oliveira MG, Amigo CR, Cunha VP, Rozenfeld H. Employing the business model concept to support the adoption of product–service systems (PSS). Ind Mark Manag 2013;42:693–704. doi:10.1016/j.indmarman.2013.05.003.

[28] Neely A. Exploring the financial consequences of the servitization of manufacturing. Oper Manag Res 2008;1:103–18. doi:10.1007/s12063-009-0015-5.

[29] Baxter W, Aurisicchio M, Childs P. Contaminated Interaction: Another Barrier to Circular Material Flows. J Ind Ecol 2017;21:507–16. doi:10.1111/jiec.12612.

[30] Krikke H. Impact of closed-loop network configurations on carbon footprints: A case study in copiers. Resour Conserv Recycl 2011;55:1196–205. doi:10.1016/j.resconrec.2011.07.001.

[31] Cucchiella F, D'Adamo I, Lenny Koh SC, Rosa P. Recycling of WEEEs: An economic assessment of present and future e-waste streams. Renew Sustain Energy Rev 2015;51:263–72. doi:10.1016/j.rser.2015.06.010.

[32] Rymaszewska A, Helo P, Gunasekaran A. IoT powered servitization of manufacturing – an exploratory case study. Int J Prod Econ 2017;192:92–105. doi:10.1016/j.ijpe.2017.02.016.

[33] Ardolino M, Rapaccini M, Saccani N, Gaiardelli P, Crespi G, Ruggeri C. The role of digital technologies for the service transformation of industrial companies. Int J Prod Res 2017;7543:1–17. doi:10.1080/00207543.2017.1324224.

[34] Porter ME, Heppelmann JE. How Smart, Connected Product Are Transforming Competition. Harv Bus Rev 2014;92:64–89.

[35] Baines T, W. Lightfoot H. Servitization of the manufacturing firm. Exploring the operations practices and technologies that deliver advanced services. Int J Oper Prod Manag 2013;34:2–35. doi:10.1108/IJOPM-02-2012-0086.

[36] Pialot O, Millet D, Bisiaux J. "Upgradable PSS": Clarifying a new concept of sustainable consumption/production based on upgradablility. J Clean Prod 2017;141:538–50. doi:10.1016/j.jclepro.2016.08.161.

[37] Cheng C-Y, Barton D, Prabhu V. The servicisation of the cutting tool supply chain. Int J Prod Res 2010;48:1–19. doi:10.1080/00207540802389235.

[38] Voss C, Tsikriktsis N, Frohlich M. Case research in operations management. Int J Oper Prod Manag 2002;22:195–219. doi:10.1108/01443570210414329.

[39] Lindahl M, Sundin E, Sakao T. Environmental and economic benefits of Integrated Product Service Offerings quantified with real business cases. J Clean Prod 2014;64:288–96. doi:10.1016/j.jclepro.2013.07.047.