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Product Service Systems and Circular Economy Technical Cycles
Unfolding business ecosystem through life cycle thinking and digitalization lenses

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Thesis presented at the Polytechnic School of University of São Paulo (USP) for the degree of Doctor of Science.

Supervisor: Professor Marly Monteiro de Carvalho

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Sistemas Produto Serviço e Ciclos Técnicos de Economia Circular
Desdobramento do ecossistema de negócio sob a ótica do ciclo de vida e digitalização

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À Stella, que há 1 ano e 9 meses revolucionou nossas trajetórias
nos ensinando a contemplar o dom da vida
sob uma ótica toda especial.

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ABSTRACT

Product Service System is arguably considered a more competitive business model due to its proposal to offer integrated solutions to customers (product *plus* service), towards dematerialization of offerings. In addition, for years the sustainable character of Product Service Systems has been discussed and its environmental, social, and economic development has been the result of countless research. In this work, the concept of the circular economy, specialy the circular economy technical cycles are considered a proxy to sustainability.Its dissemination is relatively recent and has drawn attention to the objectivity of its economic and environmental business perspective. However, the connection between these themes in the academic literature is still weak, despite the great potential of integration of these concepts. In addition, the moderating factor of digitization and life cycle thinking are fundamental variables for the development of new business opportunities within a perspective of interdependence between the multiple stakeholders, i.e. in the business ecosystem. For this analysis, healthcare and agricultural environment was selected due to its importance, complexity and under exploration. Thus, the general objective of the thesis is to propose a framework for the integration of circular economy technical cycles in the business ecosystem of product service systems. More specifically, the research seeks to: (i) analyze how the integration of circular economy technical cycles into PSS offerings can contribute to more sustainability-related outcomes; (ii) analyze the moderating effect of digitization and life cycle thinking on delivering PSS; and (iii) identify in the healthcare business ecosystem the contextual factors that affect PSS settings. For this, the first phase of the thesis includes the initial theoretical framework, obtained through systematic literature review (paper 1) and exploratory case study (paper 2). Then, the second phase addresses the definition of the conceptual framework through in-depth research connecting the research gaps identified in the previous phase (paper 3). Finally, the third phase relates to an exploratory field research, aligned with the propositions of the previous phases within the healthcare business ecosystem universe (papers 4 and 5). Thus, this research results suggests that outcomes in the healthcare sector are highly dependent on the context and that its orchestration is still far from being conducted for the primary user of the ecosystem, the patient.

Keywords: Product Service Systems (PSS), Circular economy (CE), Sustainability, Digitalization, Lifecycle Thinking.

RESUMO

Sistema Produto Serviço é indiscutivelmente considerado um modelo de negócio mais competitivo, devido a sua proposta de oferecer soluções integradas aos clientes (produto *mais* serviço), culminando na desmaterialização das ofertas. Neste trabalho os ciclos técnicos de economia circular são considerados proxy de sustentabilidade devido à objetividade de seu direcionamento econômico e ambiental sob a perspectiva empresarial do modelo de negócio. Entretanto, a conexão entre estes temas na literatura acadêmica ainda é tênue, apesar do grande potencial de integração. Adicionado a isso, o fator moderador da digitalização e do pensamento de ciclo de vida são variáveis que apesar de pouco pesquisadas são fundamentais para o desenvolvimento de novas oportunidades de negócio dentro de uma perspectiva de interdependência dos múltiplos *stakeholders*, ou seja no ecossistema de negócio. Para esta análise, o ambiente de *healthcare* e de *agricultura* foi selecionado devido a sua importância, complexidade e baixo número de publicações sobre o assunto. Assim, o objetivo geral da tese é propor um framework para integração dos ciclos técnicos da economia circular no ecossistema de negócio de sistemas produto serviço. Mais especificamente, a pesquisa busca: (i) analisar como a integração de ciclos técnicos de economia circular pode colaborar em ofertas de PSS; (ii) analisar o efeito moderador da digitalização e do pensamento sobre o ciclo de vida na entrega de PSS; e (iii) identificar no ecossistema de negócios de *healthcare* e *agricultural* os fatores contextuais que afetam as configurações do PSS. Para isso, a primeira fase da tese inclui um quadro teórico inicial, obtido por meio de revisão sistemática da literatura (artigo 1) e estudo de caso exploratório (artigo 2). Em seguida, a segunda fase aborda a definição do framework conceitual através de uma pesquisa aprofundada conectando as lacunas de pesquisa e temas sub explorados identificados na fase inicial (artigo 3). Finalmente, a terceira fase exploratória, alinha as proposições das fases anteriores dentro do universo de ecossistema de negócio de *healthcare* (artigos 4 e 5*)*. Com isso, a pesquisa sugere que os resultados relacionados à sustentabilidade no setor de *healthcare* são altamente dependentes do contexto em que o negócio está inserido e que a sua orquestração ainda está longe de ser conduzida para o principal usuário do ecossistema, o paciente.

Palavras-chave: Sistemas Produto Serviço (PSS), Economia Circular (EC), Sustentabilidade, Digitalização, Ciclo de Vida.

FIGURES

TABLES

ABREVIATIONS

B2B	Business-to-Business
B2C	Business-to-Consumer
BE	Business Ecosystem
CE	Circular Economy
DT	Digital Technologies / Digitalization
GO	General Objective
ISO	International Standard Organization
HC	Healthcare
LC	Lifecycle
PSS	Product Service Systems
PO	Product Oriented PSS
RO	Result Oriented PSS
RQ	Research Question
SBM	Sustainable Business Model
SLR	Systematic Literature Review
SO	Specific Objectives
TBL	Triple Bottom Line
TC	Technical Cycles
UO	Use Oriented PSS
WoS	Web of Science

CONTENT

PART I - INTEGRATIVE THESIS OVERVIEW

1 INTRODUCTION

The efficiency move is not something new. There were many moves to look at the waste with recycling possibilities. Yet at this point, mankind has realized that proper waste prevention is only possible with good design and monitoring of industrial activities (BARTL, 2014) over the whole life cycle of any product or service. Product/Service lifecycle thinking in this sense is fundamental to ensure more favorable conditions towards sustainability. Since the mental conception, from the design of the goods, until the end of life, provide conditions for enabling easier disassembly, adaptation for reuse, maintenance and further. An alternative economic mindset based on reconditioning, remanufacturing and recycling (GREGSON et al., 2015) complement the pre-requisites necessary to boost a shift in the production patterns and earth's health.

In this sense, circular economy can be understood as an idea that if well implemented has the potential to enable humankind to face the increasing limitations of Earth's natural resources (MEADOWS, RANDERS, MEADOWS, 2004), transforming the challenges of limitations into a new path towards the transition to production and consumption for sustainability (COOPER, 2005).

Among firms and practitioners, the concept of circular economy has been disseminated by the Ellen MacArthur Foundation as a restorative system or regenerative by intention and design (MACARTHUR, 2015) and driven by four principles: (i) waste is equal food; meaning that restorative loops is the central idea, (ii) building resilience through diversity, (iii) creating energy from renewable resources, and (iv) thinking in systems (MACARTHUR, 2013).

Adding to this idea, the shift from traditional manufacturing model (that aims at selling products as the main strategy) towards the offer of an integrated solution "a marketable set of products and services capable of jointly fulfilling a user's need" (MONT, 2002a, p.238).capable of address economic, environmental and social aspects through integration are key aspects of a Product Service System (PSS) implementation. Furthermore, PSS can be described as " the result of a strategy that seeks to optimize the performance of a system through supporting users and other stakeholders in the post-production life cycle stages" (Kjaer et al., 2016, p.95). In other words, means to improve the use phase through different services such as intensified use, improved availability of the product (through intensive maintenance processes) or through multiple users of the same product (GRÖNROOS, 2011).

Particularly, digital technologies (IoT, Big Data, analytics, cloud computing) have played an enabler role for PSS and circular economy integration (BRESSANELLI et al., 2018). They collaborate by remotely monitoring PSS performance, which directly influences an extension of the product life cycle. Moreover, digital technologies help with the equipment tracking control, making take back, end of life and closing loops processes more feasible (ARDOLINO et al., 2018).

Within this confluence of ideas, the stakeholders' network interactions emerge as a necessity to understand the interdependent relationships responsible for hindering and fostering actions that drive sustainability-related outcomes. In this sense, the influence of the Business Ecosystem (BE) configuration plays a fundamental role "to boost solutions to a more sustainable level" (GUZZO et al., 2019). According to Amor et al. (2018) the multi-actor perspective deployment, differently from the usual one-sided PSS evaluation (customer point of view or provider perspective) is mandatory in order to manage the economic, organizational and new social infrastructure transitions to support the desired environmentally benign performance (KJAER et al., 2016). Thus, to reach this intent, the PSS network value must be intensified and the policymakers added into this multi-actor perspective (MONT, 2002b).

In this sense, the operationalization of sustainability through circular economy principles and technical cycles into PSS offerings has been faced as an interesting alternative to integrate "economic prosperity, environmental quality, and social equity" (ELKINGTON, 1997; MACARTHUR, 2013).

1.1 Research Relevance

The application of a more sustainable Product Service Systems (PSS) in developing countries is still an underexplored area since they have to face the challenge of balancing economic growth with social and environmental considerations (NNOROM; OSIBANJO, 2008). According to Shokohyar et al. (2014), many developing countries are consumers of imported products from other countries, especially high tech embedded products/equipment. Such situation has as a consequence that only the consumption and the EOL phases occur in these countries. In this circumstance, theoretically, the manufacturers and their representations tend to introduce more sustainable PSS schemes to manage usage and EOL phases.

Regarding the circular economy idea, there are some dimensions which the understanding is still under construction, and which deployment is still absent from research accomplishments, such as the legislative, institutional and cultural issues (EZZAT, 2016). Regarding their influence in social discussion, these missing dimensions are considered to present major challenges to transitioning towards a circular economy; instead, they remain supporting the linear economy (HOMRICH et al., 2018).

Another aspect is the life cycle thinking approach and the lack of feedback loops from the EOL and MOL stages when designing, developing or improving products and services (JUN; KIRITSIS; XIROUCHAKIS, 2007), which hinders the development of more integrated sustainable solutions. Thus, to address this aspect approaches on how to effectively capture, manage and share product lifecycle information and data are still mandatory and not properly addressed yet (WUEST; WELLSANDT, 2016). Besides, the role of digitalization within the service transformation is still an underexplored theme (ARDOLINO et al., 2018) implying in a lack of awareness or appreciation of the information and communication technologies that are enabling many product-centric service offerings to occur in practice (LIGHTFOOT; BAINES; SMART, 2013).

Another gap identified in research refers to the understanding of the way a company "orchestrate business model change at the firm and ecosystem levels to achieve transformation toward circular economy paradigm" (PARIDA et al., 2019). In other words, the collaborative role of service partners, third-party suppliers, customers, government, regulatory agencies, and even other providers to profitably deliver the new business model (PARIDA et al., 2014).

The analysis of this "business ecosystem" aspect was chosen to be performed in field research through the lenses of the healthcare sector, which, per se, is an underexplored field regarding the PSS approach (XING; RAPACCINI; VISINTIN, 2017). Given the fact that the convergence of the mentioned research streams: product-service systems embedded with circular economy technical cycles towards more sustainability-related outcomes influenced by the moderating effect of life cycle thinking and digitalization is unique, the mapping of the roles and players of the health business ecosystem complement the complexity of these subjects.

1.2 Research Objectives and Question

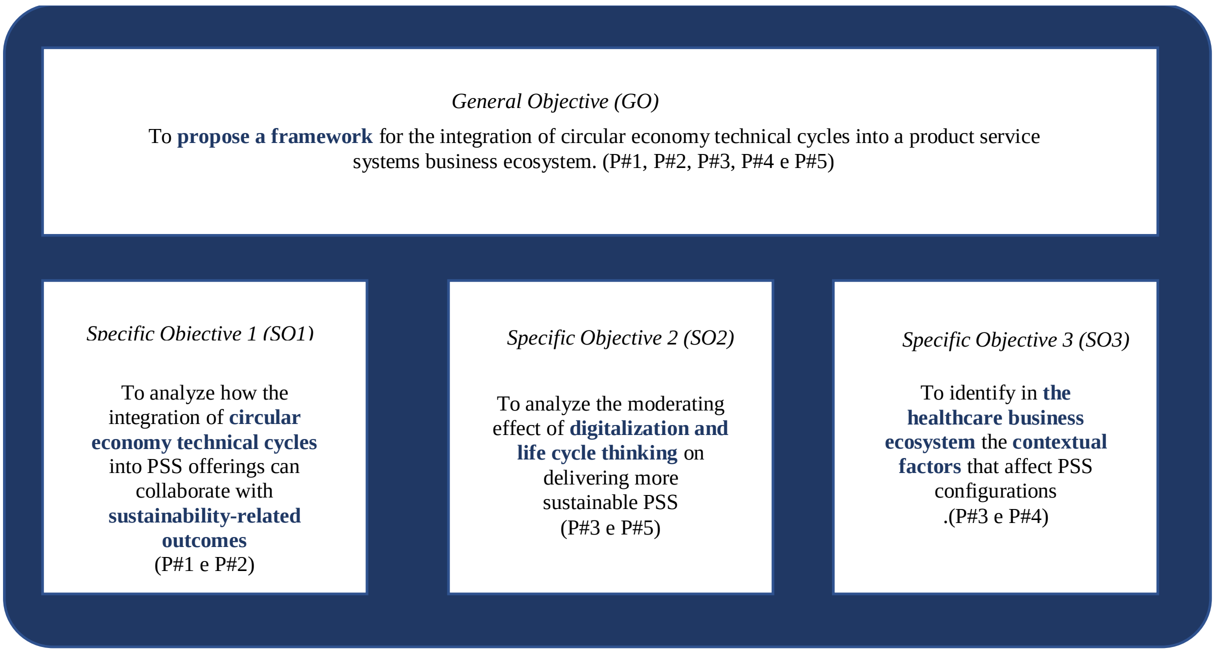
Previous researches pointed out gaps in PSS and Circular Economy literature in the context of Sustainability. The first is a business model offering a bundle of products and services in different gradations. Meanwhile, the second is interested in narrowing, slowing and closing the loop of resources towards embedding economic, social and environmental value into the business ecosystem. This thesis aims to address a combination of these research streams. In this sense, the thesis research question that arises is:

How can circular economy technical cycles be integrated into the Product-Service Systems business ecosystem?

To answer this question, the general objective (GO) of this thesis is to propose a framework for integration of circular economy technical cycles into a product-service systems business ecosystem to reach more sustainability-related outcomes.

The GO is deployed into the following specific objectives (SO): SO1 is to analyze how the integration of circular economy technical cycles into PSS offerings can collaborate with sustainability-related outcomes; SO2 is to analyze the moderating effect of digitalization and life cycle thinking on delivering more sustainable PSS; SO3 is to identify in the healthcare business ecosystem the contextual factors that affect PSS configurations. Figure 1 illustrates the GO and SOs.

Figure 1: General and specific objectives of the research



1.3 Thesis Structure

This is an article-based thesis format. It has two parts: I - Integrative thesis overview and II - Thesis' papers. Part I of this document is dedicated to present and discuss the integration of each publication towards addressing the research objectives of the thesis. Part I is composed of five sections. This first section brings the context of the research, alongside with justification, research objectives and structure of the present document. Section 2 presents a brief delimitation of the main concepts used to build the thesis, structured into four sub-sections: circular economy technical cycles (CE), product-service systems business models (PSS), PSS and CE principles as part of the strategy towards sustainability; lifecycle thinking and digitalization in the PSS context. Section 3 follows describing the thesis' research method, composed mainly by a systematic literature review and case studies. Section 4 presents how the main results from each paper integrate to each other towards addressing the thesis objectives. Next, Section 5 closes Part I providing the main research conclusions, limitations, and indications for future studies. Despite the main structure of the thesis is traditional, it is composed by arguments that retrieve the papers and, when suitable, respective sections and paragraphs, in order to develop an integrative discussion amongst the individual papers. Further content of each publication can be consulted in its specific section.

Five papers compose this thesis (listed in Table 1 and presented in Part II from Section 6 to 10). From the five publications used in this thesis, one of them (#P1) was published in the Journal of Cleaner Production (HOMRICH et al., 2018) ; #P2 was presented in 2017 during the 9th CIRP IPSS Conference: Circular Perspectives on Product/Service-Systems (HOMRICH; SATTLER; CARVALHO, 2017); #P3 was re-submitted to the Journal of Cleaner Production attending reviewers comments; #P4 was submitted to the Journal Resources, Conservation and Recycling and P#5 was submitted to the Journal Technological Forecasting and Social Change.

Table 1: Publications composing this thesis

#	Journal / Conference	Paper title	Research Method	Objective	Authors
#1	Journal of Cleaner Production (2018, published)	The circular economy umbrella: Trends and gaps in integrating pathways	Systematic literature review	GO, SO1	Homrich, Galvão, Abadia, and Carvalho
#2	9th CIRP IPSS Conference: Circular Perspectives on Product/Service-Systems (2017, published)	PSS creating business for sustainability: the Brazilian Olive Oil case in Mantiqueira Community	Case Study	GO, SO1	Homrich, Sattler, and Carvalho
#3	Under Review in the Journal of Cleaner Production (Resubmitted according to reviewers comments)	Connecting PSS in Healthcare with the circular economy idea a “hop on-hop off” experience from literature	Systematic literature review	GO, SO1, SO2, SO3	Homrich and Carvalho
#4	(Submitted to the Technological Forecasting and Social Change)	Who orchestrate Product Service Systems (PSS)? An investigation of the Brazilian Health Business Ecosystem	Case Studies	GO, SO1, SO2, SO3	Homrich, Facin, and Carvalho
#5	(Submitted to the Resources, Conservation, and Recycling)	How are product-service systems helping the healthcare sector to face the challenge of circular economy?	Case Studies – Cross-country	GO, SO1, SO2, SO3	Homrich, Evans, and Carvalho

2 DELIMITATION OF THE MAIN CONCEPTS

This section presents an overview of the main concepts addressed by this thesis' research: (i) CE technical cycles; (ii) PSS business model; (iii) PSS and CE principles as part of the strategy towards sustainability; and (iv) Life cycle thinking and digitalization in the PSS context. This part corresponds to an overview, since more details are presented throughout the articles.

2.1 CE Technical cycles

As argued by #P1 (Section 2, paragraph 3); #P3 (Section 2.2); #P5 (Section 2.2, paragraph 1). the circular economy (CE) is characterized as an economy that is restorative and regenerative by design in which products, materials, and resources are maintained in the economy for as long as possible, and the generation of waste is minimized (MORLET *et al.*, 2016), The concept of closed loops is one of the most frequently mentioned aspects related to CE. It distinguishes between technical and biological cycles and in many cases, the implementation of CE in companies requires changes in their business models, which can be reached through PSS, for instance (PAGOROPOULOS *et al.*, 2017). The biological loops are more aligned to environmental and biology backgrounds, while technical loops are more aligned to economic and industrial perspectives. (MACARTHUR, 2013). Taking those two loops in consideration, (GEISSDOERFER *et al.*, 2017, p. 759) proposed that CE is "a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops, which can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling." In other words, CE aims to eliminate 'waste', either by product life extension or by 'looping' the product or its constituent materials back into the system to be reused. (KANE; BAKKER; BALKENENDE, 2018). Due to its intrinsic complexity, CE has numerous attempts to be defined, one comprehensive definition based into a semantic analysis of previous definitions is proposed, according to #P1 (Section 4.4, paragraph 6): "*CE is a strategy that emerges to oppose the traditional open-ended system, aiming to face the challenge of resource scarcity and waste disposal in a win-win approach with economic and value perspective*."

According to Ellen Macarthur Foundation (2015), there are four technical cycles in the circular economy idea, which are: (i) repair and maintain (prolong); (ii) reuse and redistribute;(iii) refurbish and remanufacture and (iv) recycle. These elements are in-depth analyzed through the light of the healthcare system within #P4 and #P5.

2.2 PSS Business Model

According to Osterwalder et al. (2005), business models are the representation of the business logic definition regarding the companies' strategies, operations, and relationships. In this sense, PSS is considered a business strategy of providing integrated products and services to satisfy a customer's need (MONT, 2002a). Despite the several definitions of PSS this thesis adopt the following PSS definition "a business model focused toward the provision of a marketable set of products and services, designed to be economically, socially and environmentally sustainable, with the final aim of fulfilling customer's needs" (ANNARELLI; BATTISTELLA; NONINO, 2016, p.1017). The key idea behind PSS is that consumers demand the utility provided by products and services in an integrated manner, not the product per se (BAINES et al., 2007). It ends up adding more complexity to the offer since the impacts over the entire life-cycle of service and the related product must be also taken into consideration (WANG; LI.; WU; XU; SONG, 2011). Adding to that, note that the identification of the changes required in the business of companies adopting PSS is one of their main challenges, which derive from the difference between the PSS and the traditional way of developing and selling products, in fact, they are distinct business from each other (BARQUET et al., 2013).

Though experts have different opinions on the definition of PSS (ANNARELLI; BATTISTELLA; NONINO, 2016), most of them assume the same PSS categorization (TUKKER, 2004), or business models (REIM; PARIDA; ÖRTQVIST, 2015): product-oriented PSS; use-oriented PSS and result-oriented PSS, according to the evolution of the PSS towards a more servitized offer (WANG; LI.; WU; XU; SONG, 2011). PSS evolution would follow this gradation scale, from the closest to usual product-dependent business (PO) to the most service and performance-dependent business (RO). According to Beuren et al. (2013); Tukker (2004) and Neely (2009): the first (PO), has its focus in selling a product that comes with extra services, e.g. maintenance services or consultancy (after sales). The second (UO) the product is still central and not sold to the customer; however the use or availability is offered for an specific time in which the provider is paid periodically, e.g. bike-sharing or equipment renting. The third (RO) the customer pays for the agreed with the supplier upon result; e.g. "pay-per-use", energy management services, healthcare laboratory equipment leasing. In any of the PSS categories, the provider extends the stewardship to cover more life cycle stages elements than usual sale, such as the use stage and end-of-life (BAINES et al., 2007).

As a core concept for the present research, the PSS concept was discussed by various papers composing this thesis. Like an SLR, #P1 although focused in the CE definition brings insights on the gaps needed to be fulfilled such as the one related to the deployment of circular economy throughout the business model field (#P1, section 5, paragraph 7), by translating it into the offer of PSS solutions. #P2 evidence an example of an RO through a case study analysis within the Mantiqueira community (#P2, section 4), bringing an initial attempt to bridge the concept with the CE idea, yet though the biological cycle. #P3 also present PSS concepts further exemplified through its distribution into three PSS levels: operational, tactic and strategic (#P3, 2.1, paragraph2), based on specific SLR with focus in the healthcare sector. #P4 and #P5 also evidence the difference of the categories, by presenting case studies within organizations developing a set of different types of PSS within HC.

2.3 PSS and CE principles as part of the strategy towards sustainability

Sustainability permeated the thesis' research throughout all the papers. Within this thesis, the definition adopted to sustainability is "the balanced integration of economic performance, social inclusiveness, and environmental resilience, to the benefit of current and future generations." (GEISSDOERFER *et al.*, 2017, p. 766). Also based on the triple bottom line (TBL) idea (ELKINGTON, 1997). As previously stressed, PSS aims to facilitate the transition to a system in which products, services, support infrastructure, and networks are designed to serve consumers by providing them with quality of life, along with a potential minimization of environmental impacts due to changing consumption patterns (MONT, 2002a). In this sense, one of the many values added of PSS lies in their potential to decouple consumption from economic growth (KJAER; PIGOSSO, 2018), as they offer the possibility of meeting more needs with lower material and energy requirements.(GEET et al., 2015). Paper #P2 (Section 4.1 to 4.3) stresses the analysis of a RO under the sustainability lenses.

Most PSS studies consider that their implementation mandatorily generates environmental benefits. However, recent studies have recognized that in some cases they may even have a negative effect on the environment, retaining only economic benefits, the so-called "rebound effect" (KJAER; PIGOSSO; MCALOONE, 2016). Nonetheless, to achieve sustainability through PSS, numerous barriers can be identified, such as the need of changes in enterprise organization and collaborators' mindset, ownerless consumption education to customers, close collaborative relationship with partners, collaborative product-service development, and further (WANG; LI.; WU; XU; SONG, 2011). Regarding this issue, field research presented in #P4 (Section 4.3) and #P5 (Section 5.1) many of these aspects in the interconnection between the stakeholders and the context elements.

This requires different ways of thinking and working throughout the product design stage and procurement process and supply chains, continuing through to the end of the products life, acquiring experience on how to encompass all important aspects of the life-cycle and putting the adequate organizational and business models in place (GEET et al., 2015). In this context, the ability to address economic, environmental and social aspects through integration is a key aspect in the development of successful business models (LOZANO, 2008)

In fact, the literature suggests that by migrating from traditional product-focused business models to usage/result-focused ones, the potential for the circular economy increases. According to Kjaer and Pigosso (2018), the first step to move a PSS to a more sustainable business (regarding a relative resource reduction) is to improve the CE strategies throughout the PSS life-cycle. That is, make use of PSS enablers towards resource reduction, such as operational efficiency (support, maintenance), product longevity (maintenance, take-back, EoL management), intensified product usage (sharing), product system substitutions (sharing, EoL management, and optimized results).

Some fundamental challenges to improving PSS towards CE are related to the fragility of the mechanisms of its economic viability (GENOVESE et al., 2017) by utilizing circular rather than linear supply chains; the main strategy is to re-target production processes following a pattern of enhanced sustainability features (YUAN, BI, AND MORIGUICHI, 2006). This means that to achieve sustainable performance, sustainable operations need to integrate economic, environmental and social issues into its business processes. In other words, it should include the reducing of materials in designing, manufacturing, transporting, recycling, reusing and remanufacturing of products. (WU et al. 2017; KLEINDORFER, SINGHAL AND WASSENHOVE, 2005).

Note that the circular economy is mostly driven by resources better use opportunities and reduction of waste and emissions with circular rather than the linear make-use-dispose system, whose the main beneficiaries are usually the economic actors that implement the system, with emphasis on governments and companies (GEISSDOERFER *et al*., 2017). Furthermore, in this context, the three CE principles must be stressed. The first principle is the necessity to increase the utilization of assets and products, thus pursuing resource efficiency: “Preserve and enhance natural capital”. The second principle is the extension of the lifespan of products:” Optimize resource yields”. The third principle is to close the loop, enhancing multiple product lifecycles of reuse, remanufacturing, and recycling: “System effectiveness” (KALVERKAMP *et al.*, 2017, p.1539).

The implementation of the CE propositions may lead towards sustainability, since the latter provides a broader framing, open-ended with limits to optimization, which can be adapted to different contexts and aspirations, according to contextual differences, however, not always all the three pillars are balanced. (GEISSDOERFER *et al.*, 2017).

Regarding the PSS context, environmentally sustainable implies that the producing and consuming activities of PSS elements are more capable of resisting resource foundation than the existing product, which has a similar function to PSS. Economically sustainable implies that the PSS is sustainably operational, fulfilling the economic motivation of each stakeholder structurally. Socially sustainable implies that the PSS is sustainably and actively acceptable to socio improving public welfare without invalidating social justice.

Besides, the relationship customer-provider play a key role in a sustainable PSS, in fact, all partners in the extended value creation network should collaborate in coordination avoiding insufficient consideration of the influences of products and services mutually. In this sense, for a proper PSS development, the life cycle oriented management of product and service is fundamental (WANG *et al.*, 2011). This aspect is subjacent to all the paper that compose this thesis.

2.4 Lifecycle Thinking and Digitalization in PSS context

In an information economy where information is increasingly exchanged, such as currently, data collection technology has emerged with the fast improvement of IoT (Internet of Things) and telecommunication technologies (LIM *et al.*, 2018). Their main functionalities are suggested by Bressanelli *et al.*, (2018) as: improvement of product design, attraction of target customers, monitoring and tracking of product activity, offering of technical support, providence of preventive and predictive maintenance, optimization of the product usage, upgrade of the product, enhance of renovation and end-of-life activities. Digital technologies are then, critical enablers of the transition to CE at each life cycle stage (LEWANDOWSKI, 2016; BRESSANELLI *et al.*, 2018). However, the maturity of digital technologies within the life cycle stages are, nevertheless, still questionable (PAGOROPOULOS *et al.*, 2017). In this sense, paper #P3 identified a set of academic literature (#P3, Section 5) that suggested a technical approach towards intense use of digital technologies, and higher sustainability related-results in PSS and CE implementation. This proposition, during field research was not confirmed due to the business ecosystem influence #P5 (Section 4.2.3 to 4.2.5)

The mentioned technological functionalities are most related to the middle of life (MOL-product's distribution, use, and maintenance) (BRESSANELLI *et al.*, 2018). Organizations investing in digital technologies with the focus on closing the loop need to make efforts at the beginning of life (BOL-design and production) such as design-for-remanufacturing; design-for-recycling (GO *et al.*, 2015; BAKKER *et al.*, 2014), or specifically at the end of life (EOL – reuse, remanufacturing, recycling, disposal) through reverse logistics (KUMAR; PUTNAM, 2008).

Therefore, intelligent assets and connectivity are fundamental to operationalize the circular economy (MORLET *et al.*, 2016), especially by optimizing forward material flows and enabling reverse material flows (PAGOROPOULOS *et al.*, 2017). Knowing how customers are using the installed products can also assist companies to improve marketing activities and target new customers (RUST; HUANG, 2014). Furthermore, personal advice may be offered to optimize usage phase, reduce energy consumption, and upgrade digital elements (RYMASZEWSKA *et al.*, 2017), in the case of smart products. Regarding end-of-life, companies can access real-time product location and condition (FRANCO, 2017), for better execution of collection, refurbishment, remanufacturing and recycling activities (LEWANDOWSKI, 2016; BRESSANELLI *et al.*, 2018).

3 RESEARCH DESIGN AND METHODS

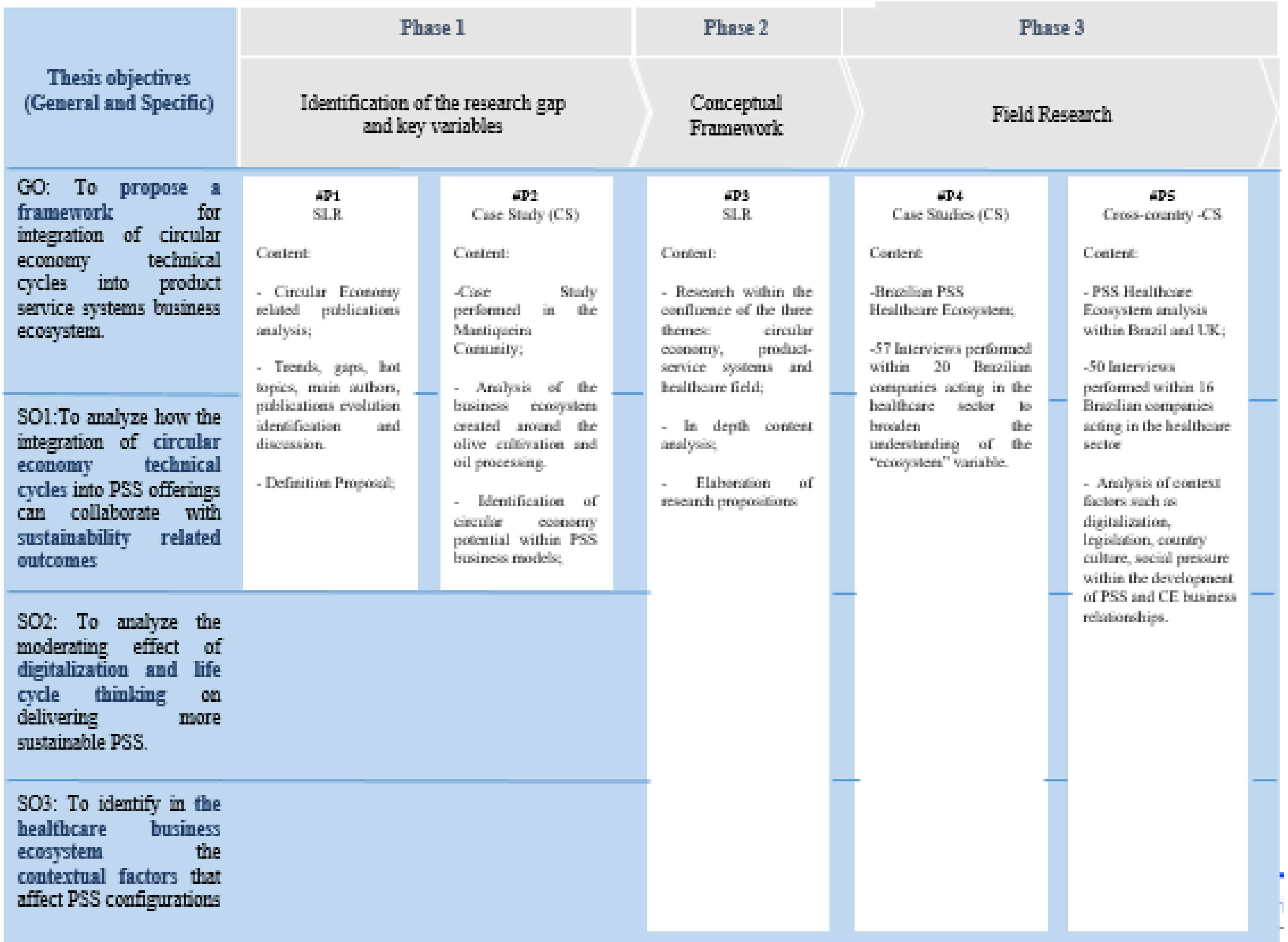
The necessity of multidisciplinary knowledge required by sustainability-related research, which is the case of the CE and PSS (KJAER; PIGOSSO, 2018), is unquestionable (KOMIYAMA; TAKEUCHI, 2006). Adding to it, the level of complexity of such a theme, permeating almost all fields of operations management demand both, more empirical research, which is based on data from the real world (FLYNN et al., 1990) and a multi-methodological approach to face and advance theory and practice (CHOI; CHENG; ZHAO, 2016). With this in mind, different research approaches were employed in the different stages of this research piece to enhance integrity and connect research with practice (SODHI; TANG, 2014).

The thesis research design comprehends the integration of the research approach and methods (white) to achieve the research objectives (left column). The research phases, respective papers and research objectives that each paper aim to address are synthesized in Figure 2.

The three phases performed during the thesis development were: (1) research initiation with broader understanding of the research theme, identification of the research gaps, exploration of the key variables composed by individual investigations on CE (#P1) and PSS (#P2); (2) conceptual framework development (#P3); (3) field research (#P4) and (#P5).

Two methods are adopted: a systematic literature review (SLR) and multiple case studies (cross-case and cross-country), even though each phase focused on a different set of aspects, refined during the thesis evolution. The SLR, unlike regular reviews, is expected to reduce bias related to a field of knowledge, since the systematization of the method allows the literature analysis to be performed and replicated by any researcher (TRANFIELD; DENYER; SMART, 2003). Multi-methods such as bibliometrics, content analysis and social network analysis based the SLR according to previous SLR indications (CARVALHO; FLEURY; LOPES, 2013; DURIAU; REGER; PFARRER, 2007). Computer-aid approach was applied through the use of the software VOSviewer (VAN ECK; WALTMAN, 2010), Sitkis (SCHILDT, 2006) and Ucinet (BORGATTI; EVERETT; FREEMAN, 2002) to support the network analysis, and the software NVivo (BAZELEY; JACKSON, 2013), Tropes (MOLETTE; LANDRE, 2010); Minitab (MINITAB, 2014), Excel, and Access to support the content analysis.

Figure 2: Research phases



Multiple case studies approach were also performed to ground theory generation (KETOKIVI; CHOI, 2014), according to recommendations of the literature (EISENHARDT, 1989; YIN 2013; SIGGELKOW, 2007). Case study method applies to this research due to the complexity, context-dependent and contemporary aspects of the thesis main subject (YIN, 2010) which is the integration of circular economy technical cycles into PSS business ecosystem to reach more sustainability-related outcomes. To reach an in-depth understanding of this specific theme (SIMONS, 2009), the main data sources used were: interviews with practitioners from companies involved in PSS business models, which were triangulated with a set of internal and external/public documents and reports. These interviews, once allowed, were recorded, transcribed and validated to further analysis and codification, performed with the help of the software NVivo (BAZELEY; JACKSON, 2013). Confidentiality of companies and interviewees were maintained throughout the whole research process.

As illustrated in Figure 2, Phase 1 encompasses an SLR with focus in CE literature, resulting in #P1, which evidenced an initial connection possibility between CE and PSS. Adding to this phase, a case study was performed with focus in PSS, resulting in #P2, which clarified the intrinsic relationship between PSS and CE idea. #P1 proposes a delimitation of the CE concept by converging the main definitions identified during the SLR (#P1, section 4.4) and also evidences few research papers linking CE “loops” with partnership/alliances aspects, bringing initial insights about the necessity of further investigation on the business ecosystem (#P1, Section 4.5). This paper also contributed to a better understanding of the CE technical cycles. Besides, #P2 comprises a PSS business model case influencing in sustainability-related outcomes in small farming communities, emphasizing the importance of the whole business ecosystem to find balanced sustainable solutions for the community (#P2, Section 4.4 and 4.5). This first phase presents the initial contributions to general objective and SO1.

In Phase 2 an SLR was performed, resulting in #P3, with the aim of deepening the investigation of the research gaps identified in the first phase, narrowing the research scope and evidencing the key-variables and the relationships between them. #P3 provides insights on the moderating effect of digitalization and life cycle thinking in the PSS development (#P3, Section 4.3.1) and in the CE principles and technical cycles deployment (#P3, Section 4.3.2) within the healthcare sector. Noteworthy the lack of connection between this conjunction of themes in the healthcare sector, also the lack of digital technologies investigation in the CE research field and HC(#P3, Section 4.3.2). This second phase and the conceptual framework descendant address contributions to GO, SO1, SO2, and SO3.

Based on evidence collected and developed in Phase 1 and Phase 2, Phase 3 is dedicated to field research. In this phase inductive exploratory research was performed within a variety of organizations belonging to the healthcare business ecosystem in Brazil and in the UK, resulting in #P4 and #P5. The sectorial cut was performed to investigate the "ecosystem" variable, throughout the PSS development stages (LC). This led to the identification of some relevant moderating aspects such as the dependency of government and regulatory policies to foster more sustainable moves throughout the whole PSS life cycle (#P4, Section 4.3). The identification of the interaction levels towards more sustainable systemic approaches and the respective stakeholders' group distribution, the barriers and enablers within the BE was also presented. #P5 is a cross-country analysis that provides insights and a broader understanding of the LC variable and the digitalization, focusing on the CE technical cycles deployment in both countries. It brings relevant discussion on the difference regarding regulatory aspects in developing and developed countries (#P5, Section 5). A strategic overview of a focal firm (PSS Provider) life cycle main processes and main stakeholders with respective CE technical cycles interdependent interactions are presented, in addition to a framework describing the pathway towards CE, relating business favourability to CE and CE technical cycles(#P5, Section 5). This third phase addresses contributions to GO, SO1, SO2 and SO3 (#P4) and (#P5).

Phases 1, 2 and 3 described previously compose the thesis research method as a whole. Table 4 presents for each paper the corresponding research method applied, describing paper aim, main data sources, selection criteria and justification for the chosen method.

Table 2: Research method for each paper.

Method	Research aim	Data sources	Selection criteria	Justification
#P1: Systematic literature review (CE)	To map CE literature, narrowing the divergent terminology and identifying research trends and gaps	664 Papers – 327 analyzed	ISI Web of Science and Scopus. Search strings: (1) topic (ISI)/ title, abstract and keyword (Scopus):"circular economy";	A large number of papers about CE: need for less biased literature analysis, robustness of the pairwise review process; Better understanding of the CE technical cycles; Gap identification: lack of papers dealing with the three themes: PSS, CE and healthcare issues.
#P2: Case study (PSS)	To investigate the influence of PSS in sustainability-related outcomes, and its challenges and benefits within a selected business ecosystem.	Case Study 9 organizations - 9 interviewees Internal and external documents	(1) Strategic relevance of PSS and sustainability results in the selected region (external documentation and regional reports); (2) Relevance of the sector in Brazil (due to the development of new business models); (3) access to internal documents and stakeholders pertinent to the research.	A better understanding of the potential of PSS to create more sustainable business models changing and forcing the whole business ecosystem to adapt; interviewees engagement; Gap identification: need to incorporate the business ecosystem in the discussion/investigation.
#P3: Systematic Literature review (PSS/CE/HC)	To analyze the literature on PSS and CE performed in the Healthcare sector, narrowing the research protocol and setting propositions for future investigation.	135 Papers – 49 analyzed	ISI Web of Science and Scopus. Search strings: (1) topic (ISI) / title, abstract and keyword (Scopus):"product-service system*" or "product-service system*"or "product-service-system*" or "Industrial Product-Service System" or "Integrated Product Service Engineering" or "Integrated product service offering") AND topic: (health*); (2) topic (ISI) / title, abstract and keyword (Scopus): ("circular econom*"or "clos* loop*"or "loop*") AND topic: (health*)	To evidence the lack of papers on the convergence of the three themes: PSS, CE, and Healthcare: robustness of the pairwise review process; Main goal: broaden the understanding of the key-variables and the relationship between them.
#P4: Case studies (PSS/BE)	To investigate the influence of the healthcare business ecosystem configuration for the development of more sustainable PSS business models	20 organizations - 57 interviewees Internal and external documents	(1) Main stakeholders groups within the business ecosystem, configuring a business relationship of interdependency, such as Large Healthcare Equipment Manufacturers (PSS Providers), governmental regulatory agency, large hospitals and clinics (PSS customers), digital technologies organizations, consulting companies, and waste management organizations	Interviewees access to explore the current Brazilian Healthcare Business Ecosystem; interviewees engagement; Main goal: broaden the understanding of the “ecosystem” variable, through an in-depth analysis of the healthcare sector.

#P5: Case studies (PSS/CE/DT)	To propose a framework towards CE technical cycles integration throughout the PSS lifecycle stages, considering the moderating effect of the stakeholders' network and the digitalization.	16 Companies (8 in Brazil/8 in the UK) 50 Interviewees (26 in Brazil / 24 in the UK)	(1) Company's belonging to similar healthcare stakeholder's network in Brazil and the UK; (2) Organizations dealing with healthcare PSS business throughout years; (3) diversified PSS agents represented by each group of stakeholders researched/interviewed	Interviewees access to explore in both countries a similar group of stakeholders; interviewees engagement; Main goal: to understand the moderating effect of the PSS life cycle thinking, digitalization, policies and regulations, business favourability to CE, etc

4 RESEARCH RESULTS

As presented in the research methods, the research results emerge from the publications and from the interaction among them. In Table 5 the contributions of each publication are summarized. This chapter discusses the individual results from each paper and their combination towards addressing the thesis' objectives. Particular attention is devoted to the core objective, which was to propose a framework for integration of CE technical cycles into PSS business ecosystem to reach more sustainability-related outcomes.

4.1 Thesis specific objectives

As mentioned in Section 1.2, the first specific objective is *SO1: To analyze how the integration of circular economy technical cycles into PSS offerings can collaborate with sustainability-related outcomes.* Mainly #P5, but also publications #P1, #P2, #P3, and #P4 corroborate to address this SO1.

This thesis shows evidence on the inclusion of circular economy technical cycles into PSS offerings to orient sustainability-related results embedded into de business ecosystem regardless of the country (as further discussed by #P5, Section 5). The research, however, points out that there are some differences between developing and developed countries, circular economy technical cycles when embedded in an environment of business favorability (regarding standards and guidelines and internal pattern within the stakeholders' network) naturally conduct to a circular economy promoting society. More about this is discussed in #P4 (Section 4.1.2, Paragraph 5).

Despite the benefits of a circular economy implementation through its technical cycles, #P1 (Section 5, Paragraph 11) emphasizes that CE transition is related to the fragility of the mechanisms of its economic viability, that is the main reason sustainable operations need triple-bottom-line (TBL) thinking (integrating economic, environmental and social issues) into its business processes. In this sense, the research thesis discusses also new business opportunities that emerge naturally from CE implementation through #P2 (Section 4.4). #P4 (Section 4.1.2) and #P5 (Section 4.2.1) to evidence that economic aspects can be a boost and balanced with social and environmental aspects.

The health care sector is in-depth analyzed and paper #P3 (Section 5, Finding 4) introduces the interdependent relationship between CE technical cycles and Life cycle thinking towards sustainability-related outcomes. #P3 has a fundamental role in creating the thesis conceptual

framework, emphasized by the gap identified in the confluence of aspects from SO1 in healthcare. Paper #P4 (Section 6, paragraph 5) brings also some insights about CE technical cycles and its deployment in PSS business models, reaching sustainability-related outcomes.
The second specific objective, *SO2, is to analyze the moderating effect of digitalization and life cycle thinking on delivering more sustainable PSS*. Publications #P3, #P4, and #P5 are devoted to broadening the understanding of the influence of LC and DT in reaching better sustainable outcomes throughout the whole life of a PSS offering.
In particular, #P3 presented the first version of the thesis conceptual framework (Section 2.4), taking into consideration the following confluence of ideas: PSS, CE technical cycles, digital technologies, and life cycle thinking. Their interaction is presented according to the scientific literature databases through *Ucinet* networks (Section4.3). In this paper it was also identified in the academic literature seven findings (Section 5) that conducted two research propositions*: (P1) The positive effect of PSS operational level (OP) on PSS outcomes (PSSP) and TBL is moderated by digital technologies such that the positive effect is greater when digital technologies are higher; (P2) CE Technical Cycles could be leveraged in healthcare if life cycle management were more intensely explored with an influence on performance aspects (business outcome and TBL).* Those propositions were further investigated through field research, resulting in #P4 and P#5.
#P4 focused on the main PSS life cycle aspects in healthcare (Section 4.1) and the main groups of stakeholders identification added to the intensity of their interaction according to each phase (Section 4.2). The identification of the different elements influencing the PSS configuration (Section 4.3) such as the government influence on digitalization and eventually in PSS business sustainability configuration, contributed to the summarized aspects regarding sustainability-related outcomes (Section 6, paragraph 4) for RO-PSS and PO-PSS configurations.
In #P5 the digitalization aspect was further explored in the sector and its sustainable consequences such as natural resources reduction, equipment use intensification, and life extension, lower carbon emissions, financial savings and so on were some of the aspects that emerged (Sections 4.2.3 to 4.2.5)
Addressing SO3, which aimed to identify in the healthcare business ecosystem the contextual factors that affect PSS configurations, the following factors were found in the literature: #P1 (Section 4.5, Paragraph 3; Section 5, Paragraph 2), #P3 (Section 5) and confirmed by the case studies (#P4, Section 4.3; #P5, Section 5): need of integrated policies, regulation implementation, legislative, institutional and cultural issues, public information and technology level. Complementing previous literature, sustainability initiatives within organizations was

also identified as another relevant context factor (#P5, Section 5). The relevance of context factors within the BE was fundamental in #P4 (Section 4.3), evidencing the main interaction levels of Healthcare BE with the respective stakeholders' group distribution. Once the main influences are punctuated and clarified, new approaches towards improvements in the whole system might be implemented.

4.2 Conceptual framework proposal

As indicated by Section 1.2, the thesis' general objective was to propose a framework for integration of CE technical cycles into the PSS business ecosystem to reach more sustainability-related outcomes. For this, Figure 3 shows an overview of the trajectory of how the ideas evolved from one paper to the other, achieving the proposed conceptual framework in #P5 (Section 5.2).

Evolving from previous papers (#P1, #P2, #P3,#P4), #P5's cross-country case studies led to the final proposed conceptual framework, combining previous knowledge with key aspects for healthcare business ecosystem that emerged from data analysis and interpretation. This framework brings refinements and contributions: (1) from #P1, which indicated the CE technical cycles and PSS business model lack of investigation and an interesting possibility for more sustainable-relates outcomes, the combination of policies and legislative, institutional and cultural issues, as they can contribute to CE deployment and to competitive advantage; (2) from #P2, which stressed the importance of the business ecosystem elements to balance all three aspects of sustainability and to reach proper implementation of PSS (BOL, MOL and EOL) towards sustainable development; and (3) from #P3 and #P4, which explicitly addressed healthcare PSS configuration, CE technical cycles, life cycle thinking and digitalization issues emphasizing the stakeholders' influence within the whole PSS life cycle. Strategic, Tactical and Operational PSS aspects compose some significate influence into PSS outcomes (Customer satisfaction and PSS performance) and Sustainability triple-bottom-line aspects.

Figure 4 shows the final conceptual framework proposed by this thesis to support the research GO, which is further discussed in #P5 (Section 5.2). The framework illustrates the idea of PSS as an evolution of traditional business models, adding more two groups of elements: the CE Technical cycles and the business ecosystem represented by the stakeholders' group around the PSS Provider life cycle main processes and main internal and external interactions.

In other words, circularity within healthcare PSSs should be thought in an integrative approach throughout the whole PSS lifecycle. Figure 4 shows the main groups of processes of each life cycle stage from a focal firm perspective (PSS provider) with an emphasis in 6 moments in which CE technical cycles concepts play a special role. The main stakeholders are represented around the focal firm and the steps in which they interact are represented by the numbers next to each group of stakeholder. For instance, it indicates that the CE technical cycle connecting the EOL phase should feedback the associated design phase of a PSS and that the ecosystem influence in this step 1 is represented by the following groups interaction: regulatory agencies, federal government policies, healthcare diagnostic companies, Hospitals/Clinics Private/public, councils associations and general consultancy.

Since revenue is crucial for PSS sustainability, CE technical cycles implementation should take this aspect into consideration to guarantee sustainability related-results. This was also pointed out by #P2 case study, which indicated profit as one of the most relevant performance criteria because it is a requirement for an organization's activities (#P2, Section 4.3and 4.4). Hence, for CE technical cycles implementation, rather than being end goals, are means to provide financial resources, which in turn enable sustainable PSS business ecosystem through the balance among each stakeholder's group influence.

The main contribution of this thesis regards to paper P#5, Figure 4. The framework presented brings insights on the overall PSS business model phases, embedded with the CE technical cicles. Circularity within healthcare PSSs should be thought of in an integrative approach throughout the whole PSS lifecycle. Figure 2 shows the main groups of processes of each life cycle stage from a focal firm perspective (PSS provider) with emphasis on 6 moments in which CE technical cycle concepts play a special role. The main stakeholders are represented around the focal firm and the steps in which they interact are represented by the numbers next to each group of stakeholders.

Step 1 – occurs during the design and project definition stages, when the prerequisites for deploying CE technical cycles are determined. The return arrow emphasizes the need of a feedback loop from equipment EOL, to design PSS increasingly more suitable to CE and sustainability goals.

Step 2 –represents the return possibilities from the EOL procedures back to the production line, through raw material (recycle), repair and reuse of materials and components, happens during the manufacturing itself.

Step 3 – corresponds to the extra inputs that should happen within the distribution and logistics processes, mainly to cope with sharing, dematerializing and intensification of the use aspects from CE, once the EOL procedures take part (each contract type has different specificities that may require more or less of this step activities).

Step 4 – represents an inner loop of the manufacturing process that can better fit CE technical cycles by reducing, recycling, reusing and repairing components and materials in the production line itself.

Step 5 - represents an inner loop within the use and maintenance group of processes (in this framework example, it was summarized into supply and operation processes group, representing the product and the service aspects of the PSS), which can better fit CE technical cycles by reducing, recycling, reusing and repairing components and materials in the operational phase.

Step 6 – corresponds to the EOL procedures, in which equipment, components, materials may feedback previous steps favouring closed loops business or reach proper environmental disposal. The main goal in step 6 is to reach the “zero” landfill mark.

Still according to the framework (Figure 2), which may represent either the Brazilian or the UK healthcare environment, the regulatory agencies and federal government policies are fundamental to foster, control and inspect steps 1, 2, 5 and 6. Second-Hand Companies may interfere in steps 2 (limiting the quantity of materials within the manufacturing processes), 5 (offering extra materials and parts for the maintenance phase) and 6 (recollecting obsolete/old equipment from the owners). Healthcare Diagnostics Companies and Hospitals/clinics also interfere in steps 1 (requiring specific design and projects) and 5 (choosing between the different strategies of use and maintenance). Furthermore, Health suppliers may influence steps 4 and 5 (especially in the internal loops of the manufacturer) and Waste Recycling Companies act in steps 4, 5 and 6. In steps 5 and 6, Health Waste Disposal Companies help in the management of the different treatment and destination that should be given to the diversity of materials gathered within the operation and EOL phases. A constant presence, sometimes directly involved in every step, is general consultancy firms that may offer their services either to the PSS provider or to the PSS contractor. They play an important role in making the infrastructure deployment of the most intensive CE projects, mainly focusing on efficiency and performance. Councils Associations (products and professionals representative entities are indirectly participating in public regulatory decisions of every step of the framework. Digitalization is spread all over the PSS lifecycle, but regarding CE opportunities, special attention must be given to step 3, which characterizes UO and RO-PSS, mandatory for distribution and logistics control during the use and users’ behaviour monitoring, which is fundamental for the dematerialization and improvement of the business. Digital Companies also take an important role in step 5 fostering reduction and repair from CE technical cycles, through digital monitoring, performance analysis, predictive maintenance through online data and optimization of resources by remotely controlling devices (IoT and analytics). In step 6, traceability of parts and devices in the EoL is already performed by original manufacturers, yet this could play an even more important role in CE, if in a near future, a common open platform could connect regulatory agencies, original manufacturers, third parties maintenance and waste management companies, as a national repository of health devices information. This would facilitate both probable trading business (reuse, refurbish, remanufacture) and proper sanction against irregularities, such as improper maintenance, lack of proper final disposal, over extension of “forbidden materials” lifecycle (belonging to “old devices”, as preconized by RhOS, WEEE and further.

Table 3: Overview of publications' contributions

Method	Main contributions
#P1: Systematic literature review (CE)	A deeper understanding of CE literature providing basis for the identification of opportunities to implementation. Proposition of a broader definition for CE, clarifying ways to its feasible implementation into business: (i) rethinking operations management, particularly products and services lifecycles (beginning of life – BOL, middle of life – MOL, and end of life – EOL), (ii) manufacturing processes; (iii) supply chain management activities, (iv) context factors (sector, country, regulation, business practices, government influence, digitalization, etc).
#P2: Case study (PSS)	Confirms through empirical evidence the influence of the PSS business ecosystem into the creation and feasibility of new business-oriented to sustainability (TBL), through the implementation of CE biological and technical cycles. Evidences three main aspects of the Result Oriented-PSS implemented in the community: (i) dematerialization; (ii) sharing; (iii) use intensification Offers insights regarding the importance of social policies led by the government to boost and balance economic, social and environmental development
#P3: Systematic literature review (PSS+CE+HC)	The bridge between PSS in Healthcare and CE in Healthcare. Identification of recent body of knowledge and research opportunities due to: (i) the lack of contributions relating PSS types and CE opportunities in Healthcare; (ii) the lack of empirical PSS approach within healthcare stakeholders network and/or business ecosystems; (iii) absent use of digitalization to enable or facilitate CE implementation. This investigation resulted in the first version of the thesis' research conceptual framework. Seven findings were highlighted and two propositions were defined for further investigation: (P1): The positive effect of PSS operational level (OP) on PSS outcomes (PSSP) and TBL is moderated by digital technologies such that the positive effect is greater when digital technologies are higher; (P2): *CE Technical Cycles could be leveraged in healthcare if life cycle management were more intensely explored with an influence on performance aspects (business outcome and TBL).*
#P4: Case studies (PSS+BE)	Presents a broad overview of the Brazilian Healthcare Business Ecosystem and the challenges and opportunities to sustainability according to Tukker's (2004) PSS business' typology: (i) product-oriented; (ii) use oriented; (iii) result-oriented. Evidence that all PSS types are developing towards sustainability, however the drivers are consistently distinct: for PO (economically driven), for UO and RO (regulation-driven)
#P5: Case studies (Cross-country) (PSS+DT)	Brings insights about the influence of the stakeholders' network and the 6 steps necessary to the implementation of CE technical cycles during a PSS lifecycle. Presents a framework based on empirical evidence from the UK and Brazil, evidencing the two pathways to reach a CE promoting society: (i) company-driven and (ii) regulation-driven. The framework relates the levels of business favorability to CE vs. CE technical cycles.

Figure 3: Roadmap of papers and frameworks

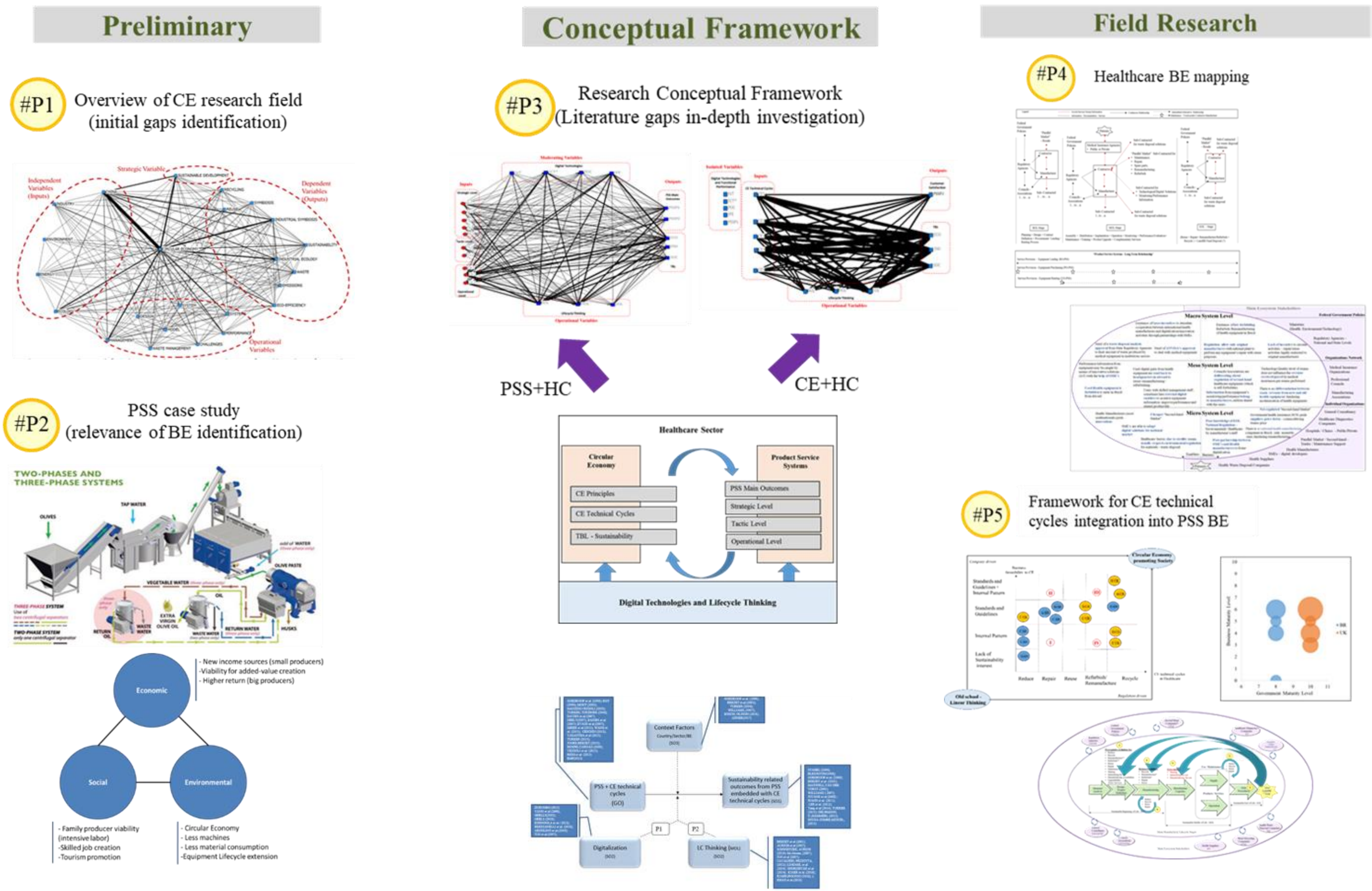
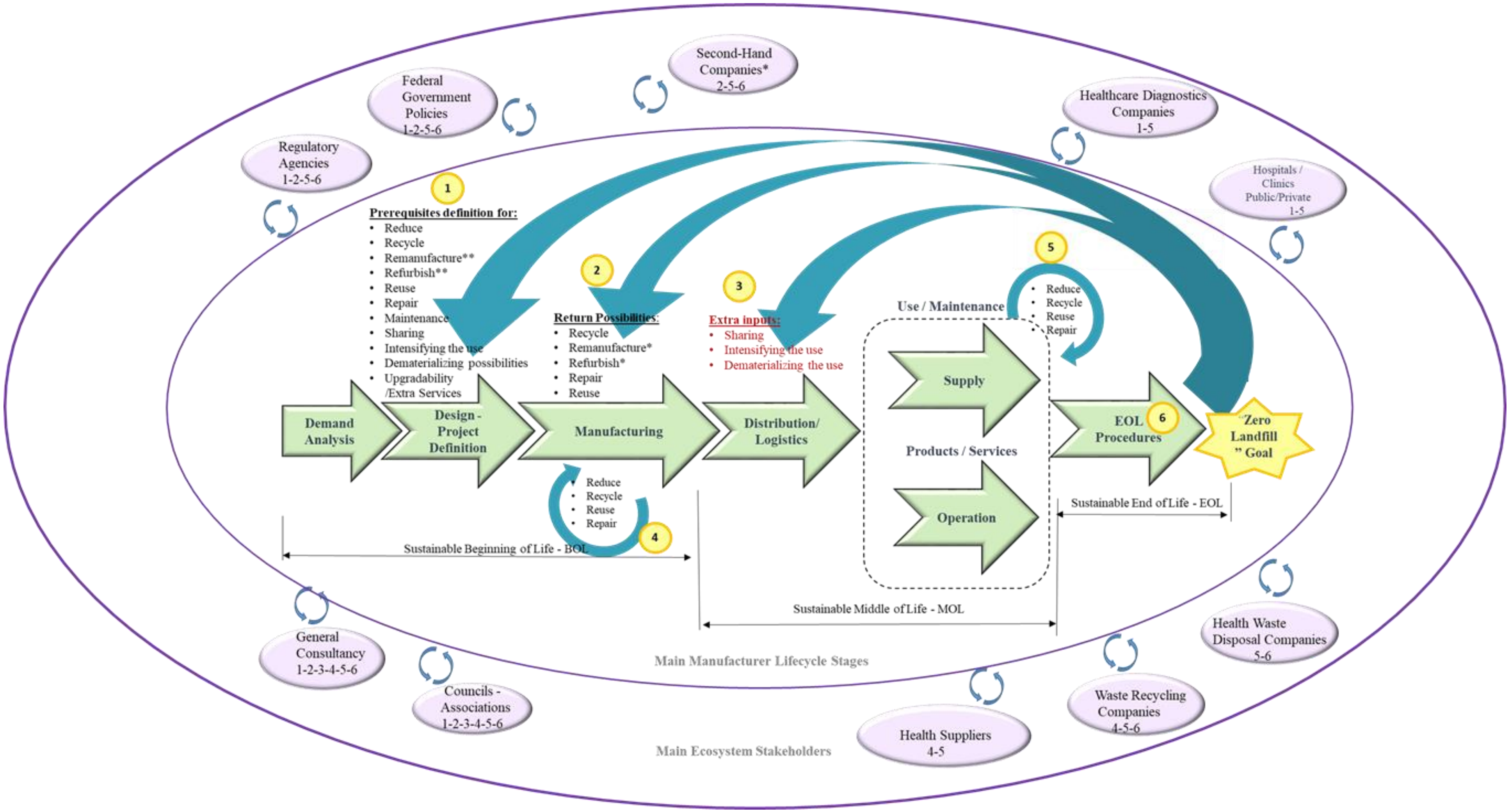


Figure 4: Conceptual framework for the CE technical cycles integration into PSS-BE



Source: #P5 (Section 5.2)

5 CONCLUSIONS, LIMITATIONS AND IMPLICATIONS

This thesis research aimed at present a framework for integration of CE technical cycles into a product-service systems business ecosystem to reach more sustainability-related outcomes. A multi-method research approach combined SLR and case studies within a total of 38 different organizations to support the research objective. The aimed framework was presented in Figure 4 and further discussed in #P5 (Section 5.2). With this framework, this research indicates also that both, internal patterns, standards and guidelines, and external influences by policies, regulation, stakeholders partnerships and interdependency (#P5, Sections 5.1 and 5.2) are fundamental to reach sustainability-related outcomes. Rather, the thesis argues that the business ecosystem is a perspective from which any organization should be critically analyzed in the context of sustainable development. From a CE technical cycle perspective, the proposed framework (Figure 4) indicates that profit even tough is not the only performance criteria, can influence positively in the systemic adoption of its practices. For that, the whole life cycle analysis and the influence of the distinct stakeholders' group composing the business ecosystem should be taken into consideration. The moderating effect of life cycle thinking and digitalization according to propositions (P1) and (P2) suggested in the paper #P3 (Section 5) were confirmed thought the light of field research (#P4 and #P5). Yet, digitalization due to BE influence (regulatory agencies, health insurance, hospitals, and clinics, etc.) is not being used in its full potential. However, it must be emphasized that for completing the various loops of CE technical cycles implementation, (steps from 1 to 6) and especially for step 3, digital technologies play a fundamental role as PSS business enablers.

This framework indicates, amongst other issues, that to reach more sustainable related outcomes, a confluence of factors must be taken into consideration, rather than just implementing CE technical cycles. The whole product/service life cycle perspective and the business ecosystem orchestration through the stakeholders' network deployment largely influence a sustainable implementation. These are non-exhaustive innovative ideas on how to implement the CE towards sustainability, however, the proposed framework (shown in Figure 4 and further discussed by #P5) intend to combine aspects of PSS-BE that address both CE and sustainability in tangible ways. On the one side, it highlights the conflicting demands that not only each BE “external member”, but also internal to the focal organization, might have (evidence from the cases suggest that indeed they have) (#P4, #P5). On the other side, the framework also stresses that to overcome the complexity of the CE technical cycles implementation, the solution lies mostly under the interdependency relationship that partnership and alliances rely on, to accomplish win-win situations for the BE integrant.

Besides the framework proposal, this thesis also contributes to further knowledge on the overlap between CE technical cycles and PSS business ecosystem approaches, indicating that research on one side has a large potential to contribute to the other. For instance, papers mainly focused on CE indicated the need to go beyond isolated, self-standing initiatives towards more systematic integration of sustainability into business, e.g., through product-service systems business (#P1, Section 5, Paragraphs 5 and 7; #P2, Section 5, Paragraph 2). The most explicit interconnected discussion between CE and PSS-BE was built by #P4 (Section 4.2 and Section 4.3) and also discussed by #P5 (Section 5.2), indicating their complementarity to support organizations to intensify their contribution to reaching more sustainable related outcomes.. This thesis showed also that CE technical cycles could serve as interesting alternative to make sustainability-related outcomes more tangible. Spreading this as a common language for academics, policymakers, non-governmental organizations, and for-profit corporations may enable and foster further synergies between them. Thus, the thesis also points out the benefits of using this terminology to delimit studies on the consequent three aspects of sustainability (economic, social and environmental balance) in the various areas of research. The research contribution of each paper separately is deeper discussed in Section 5 (#P1), Section 5 (#P2), Section 6 (#P3), Section 6 (#P4), Section 6 (#P5). Based on these publications, this thesis was able to provide contributions mainly to the CE and PSS body of knowledge towards sustainable related outcomes, but also to the BE literature.

As a main conclusion, this framework can be applied by managers or strategic stakeholders belonging to the healthcare business ecosystem to align expectations, and identify possibilities towards a better use of opportunities regarding the CE technical cycles implementation. The stakeholder’s alignment is critical to any CE activity. In this thesis context CE is considered a proxy to more sustainable-related outcomes.

5.1 Research limitations

It is important to stress that the contributions previously presented need to be considered in light of research limitations. First, SLR's (performed by #P1 and #P3) present limitations, since they are based on a selection of papers obtained from digital search engines through a specific set of search strings, filters and databases (Scopus and Web of Science) for delimiting the papers sample. Adding to that, the content analysis may generate an interpretation bias that the systematic multi-method approaches are expected to mitigate (#P1, Section 6, Paragraph 4). Moreover, the strings selection criteria may lead to taking out many important and well-known books, grey literature and proceedings papers. However, it can be considered a unique contribution in such a complex research area (#P3, Section 6, Paragraph 4). Second, case study method itself (used in #P2, #P4, #P5) also present limitations, since it is based on theoretical sampling and not necessarily represent the universe of organizations, in other words, they can not be generalized. Also, by choosing companies to study that is deeply connected to PSS implementation and defining the BE analysis through the circular economy technical cycles and sustainability lenses, the thesis results may find the need for adaptations to properly address the moderating effect of digitalization and life cycle thinking within other lenses. Besides, a third limitation connected to the implications for theory and future studies is that the thesis is closely related to private and for-profit companies since most of the case studies were performed in this type of organization, which make the results more suitable for this kind of organizations.

The fourth limitation, as in any research, is related to the thesis as a whole and regards to the bias from personal and moral values influencing not only the researcher but also interviewees and even the readers. This aspect is evidenced in sustainability research, since interviewees tend to answer the questions following social norms and expectations, giving "politically correct" answers to the aspects under study. To reduce this bias, investigation and data collection from different stakeholders group from distinct sources were fundamental to cross-analyze the evidence from each case study.

As another research limitation for the present thesis, lies on the time difference between the first and the last publications, emphasizing the time needed to the evolution in expressing the core matters on CE and PSS and eventually the influence of the BE “variable” through a sectorial analysis in the healthcare. To mitigate this, the present part of the thesis (Part I) seeks to bring this different contribution into an integrated logic and discussion, following the knowledge evolution (for example, as illustrated by Figure 3).

5.2 Implications for theory and future studies

The first contribution of this research to the theory is the identification of the main trends, themes, and gaps in literature through both systematic literature reviews (#P1 and #P3), which provided the basis of the conceptual framework of the thesis. The first by contributing to mapping of the CE recent literature and advances. The second by bridging the CE and the PSS ideas through a sectorial lens, to collaborate with both, fill a research gap and contribute to the discussion of the business ecosystem influence. The case studies (#P2, #P3 and P#4) despite the impossibility to generalization, add field information to collaborate for further theory development.

More studies using action-research as a method has the potential to provide a further understanding of the implementation challenges of CE technical cycles involving in a systematic approach the PSS business ecosystem group of stakeholders highlighted by the conceptual framework proposed by #P5 (Section 5.2, Figure 2). For this, numerous tools can be developed to promote further investigation of systematic BE influence in CE technical cycles further development towards more sustainable-related results in practice. The deployments of such an approach can be translated into improvement opportunities, deriving new research opportunities.

The proposed conceptual framework (Figure 4) brings indication of the concept of partnership and alliances, deriving from PSS business ecosystem practices, which in the limit (RO-PSS) despite the complexity, contribute to sustainability through the longevity and dematerialization idea between the customer-provider long term relationship. This notion is still emergent and can provide interesting research object for further investigations in BE sustainability sphere. Mainly because of the system-level perspective and the need for changes in mindset towards solutions that incorporate aspects beyond organization's boundaries.

Moreover, context factors were raised by the case studies (#P2, #P4 and #P5) and summarized in the "stakeholders' representation" within the proposed conceptual framework (Figure 4). Yet, future studies must be applied to deepen the understanding of the conditions under which these factors directly affect PSS performance. For this investigation, quantitative survey research method can be applied.

Moreover, the SLR's conducted by the thesis lay indication of opportunities for future research investigation on CE (#P1) and CE/PSS/HC (#P3). #P1's SLR (Section 4.5) point out the challenge of investigating CE under the business models perspective, stimulating practices to improve sustainable development and deeper understanding of the benefits and challenges of using partnerships and alliances (especially with regulatory agencies and government) to improved performance.

5.3 Implications for practice

The mapping of the main stakeholders belonging to the healthcare PSS-BE (#P5, section 5.2) and proposing a qualitative framework linking business favorability and CE technical cycles

(#P5, Section 5.1) presents a better understanding of the pathway that should be followed towards a CE promoting society. In terms of managerial implications, our research shows that the drivers that move companies towards CE, in fact, they do not have sustainability as the main goal, but as a secondary benefit. Nevertheless, environmentally, those CE actions promote the reduction of inputs use and collaborate in closing the loop with raw materials and energy. Socially and economically, besides generating many parallel jobs and influencing the care for many health patients, the main insight is that CE technical cycles are responsible for making many businesses feasible in the healthcare sector. Which emphasizes further positive effects of its implementation.

This research also has strong implications for public policy in creating and nurturing an environment that supports CE technical cycles through PSS development. Besides, the findings reveal that, in the Brazilian healthcare, conflicts of interests are one of the greatest barriers. (#P4, section 4.3). Furthermore, the identification of the barriers and enablers to face the challenge of CE and the involved stakeholders' group per system level provides information about specific aspects of the BE, helping practitioners to face clearly the business main influences.

Further practical implications of this research are the attempt to develop an adequate common language for academics' and practitioners' discussions around CE and PSS-BE, as they are complex ideas. Besides, the present research sought to clarify either for organizations or policymakers that the drivers that move companies towards CE, in fact, they do not have sustainability as the main goal, but as a secondary benefit. Nevertheless, although the BE configuration sometimes does not foster CE principles implantation, practitioners may focus their sustainability intents by addressing the aspects involved with the CE technical cycles actions deployment.

PART II - THESIS' PAPERS

6 #P1: The circular economy umbrella: Trends and gaps on integrating pathways

Journal:	Journal of Cleaner Production
Authors:	Aline Sacchi Homrich; Graziela Galvão, Lorena Gamboa Abadia, Marly Monteiro de Carvalho
Status:	Published
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Abstract

Among scholars, politicians and practitioners, the term “circular economy” (CE) has become increasingly familiar, but the concept comes from different epistemological fields and there is still a lack of consensus and convergence in the literature. This paper investigates the trends and gaps on the pathways convergence of the circular economy literature. The research method is a combination of semantic analysis, bibliometrics, networks and content analysis in a systematic literature review. The sample is composed of 327 articles extracted from the Web of Science and Scopus database. The results point out the lack of consensus on terminologies and definitions, thus, based on semantic analysis, a definition is proposed. In addition, the literature shows two main clusters, with different backgrounds, of different leading research groups in distinctive geographic regions. One cluster focuses on ecoparks and industrial symbiosis, mostly in the context of China. The second cluster is concerned with supply chains, material closed loops and business models.

Keywords – Circular economy, Bibliometric study, Qualitative content analysis, Semantic analysis, Research, Publications, Social networks, Factor analysis

Highlights

- Multi-method approach was applied mixing semantic, bibliometric and content analysis.
- Semantic analysis provides an in-depth understanding of circular economy definition.
- Two main clusters were identified, with different backgrounds and geographic regions.

- The ecoparks and industrial symbiosis cluster is mostly in the context of China.
- The cluster supply chains, material closed loops and business models cluster are increasing.

6.1 Introduction

In the academic world, among politicians, and practitioners of real-life industrial operations, the term “circular economy” (CE) is being more frequently mentioned. Circular economy can be understood as “an idea and ideal” (GREGSON et al., 2015, p.218) for facing the increasing limitations of Earth’s natural resources (MEADOWS, RANDERS; MEADOWS, 2004), facing the limitations as a new path to the transition to production and consumption for sustainability (COOPER, 2005).

Circular economy enables cyclical thinking, instead of having an open-ended conception of the value-added chain (WUEBBEKE; HEROTH, 2014), looking for “closed loops” (BOCKEN et al., 2016), or minimizing the consumption of virgin materials and energy (WUEBBEKE; HEROTH, 2014). However, “CE is emerging as an economic strategy rather than a purely environmental strategy”(YUAN, BI; MORIGUICHI, 2006), requiring a “complete reform of the whole system of human activity, which includes both production processes and consumption activities” (YUAN, BI ; MORIGUICHI, 2006). The industrial structure and industrial policies reform must be adjusted to promote new technologies development in order to reach a solution by changing the waste recycling focus (YUAN, BI ; MORIGUICHI 2006; TU et al., 2011a).

Although the expression “circular economy” still remains open, in general it must include at least the notion of inputs reduction, reuse, and recycling waste; this naturally creates the necessity of optimized networks between companies and eco-industrial parks (YU, DAVIS ; DIJKEMA, 2013), exemplified by industrial symbiosis and extended product life (GREGSON et al., 2015, p.218). In turn, the concepts within industrial ecology, such as cradle-to-cradle can be considered leading principles for eco-innovation, in which wastes are used as raw materials for new products and applications known as “zero waste economy” (MIRABELLA, CASTELLANI; SALA, 2014).

In order to move towards this new path, circular supply chain management (CSCM) is crucial, to enable new business models for the circular economy (BOCKEN et al., 2014) through the closing, narrowing and slowing of loops (BOCKEN et al., 2016) . Product lifecycle thinking is fundamental from the beginning, from the design of the goods being manufactured, to ensure favorable and enabling conditions for disassembly and adaptation for reuse. This is also reflected in an alternative economic mindset based on reconditioning, remanufacturing and recycling (GREGSON et al., 2015).

It is possible to say that the terminology around “circular economy” has been diverging rather than converging, and the term “closed loop” is often used in parallel (BOCKEN et al., 2016). Some authors also say that CE is a concept that emerged from the industrial ecology paradigm and has a closing-loop notion as its original central idea. (YUAN, BI ; MORIGUICHI, 2006). In addition, distinctive research streams coming from different epistemological fields like biology, economy, and ecology provide a conceptual umbrella such as cradle-to-cradle (MCDONOUGH ;BRAUNGART, 2002), industrial ecology (GRAEDEL; ALLENBY, 1995), and biomimicry (BENYUS, 2002).

The present study aims to narrow the identified gap by performing a mapping study, analyzing the emergent literature on the circular economy from different fields, and exploring a large sample of publications. To accomplish this objective, this paper seeks to answer the following research questions:

- *(RQ#1) What are the main research streams, the core topics, authors, and journals?*

To achieve a more complete and inclusive understanding, based on the findings from this first question, the main definitions on circular economy are identified and used to develop a more comprehensive one, by answering the second research question:

- *(RQ#2) What is the definition of circular economy?*

To further analyze the circular economy content, the most recent ideas from this research area and identify future research agendas, the third question is proposed:

- *(RQ#3) What is the most up-to-date thinking, trends and gaps in the literature?*

To answer these questions, the research design merges semantic analysis, bibliometrics, network and content analysis in a systematic literature review. The paper is organized in six sections. Section 2 outlines the concept of CE and its theoretical foundations, followed by Section 3, which presents the research design. In Section 4, the results are presented by analyzing divergences in terminology around circular economy, applying bibliometrics, semantic analysis to present a comprehensive definition of CE, followed by the content analysis to answer the research questions. Sections 5 and 6 present the discussion and conclusions.

6.2 Literature Review

The introduction of the concept of circular economy is associated with Pearce and Turner (1989) as mentioned in the papers of the following authors: Su et al. (2013); Ghisellini et al.(2016) and Geissdoerfer et al. (2017). They investigate the influence of natural resources on economic systems and the impacts of linear and open-ended perspectives.

Among firms and practitioners, the concept of circular economy has been disseminated by the Ellen MacArthur Foundation as "an industrial system that is restorative or regenerative by intention and design" (MACARTHUR, 2015) and driven by four principles: (i) waste is equal food; meaning that restorative loops is the central idea, (ii) building resilience through diversity, (iii) creating energy from renewable resources, and (iv) thinking in systems. To understand the closed loop concept, a butterfly diagram illustrates the two butterfly wings: the right is the technical and the left the biological closed loop (MACARTHUR, 2013).

However, from the academic perspective, there is a lack of consensus and various definitions of circular economy coexist, as discussed further in this paper and summarized in Appendix A. The most frequent research streams that refer to the foundation of CE are presented in Table 1. The concept of closed loops is one of the most frequently mentioned aspects related to CE; biological loops are more aligned to environmental and biology backgrounds, while technical closed loops are more aligned to economic and industrial perspectives. More recently, the fields of management and strategy are paying more attention to CE with a growing literature on circular business models (LINDER; WILLIANDER, 2017; LEWANDOWSKI, 2016; BOCKEN et al., 2016).

Table 1: Schools of thought of CE

Schools of thought	Definitions	Source	References that link with CE
Cradle-to-cradle	Products designed to regenerate the ecosystem as biological nutrients or to regenerate industries such as nutrients, components and materials in a 100% closed material loop.	MCDONOUGH ; BRAUNGART (2002)	GEISSDOERFER ET AL.(2017), LEWANDOWSKI (2016), MACARTHUR (2015), SCOTT (2013).
Industrial ecology	Cyclical resource-use patterns observed in biological ecosystems are used as a model for designing mature industrial ecosystems, whose productivity depends less on resource extraction and waste emission.	GRAEDEL; ALLENBY (1995)	GEISSDOERFER ET AL. (2017), LEWANDOWSKI (2016), MACARTHUR (2015), SCOTT (2013).
Biomimicry	Designers are inspired directly by organisms, biological processes and ecosystems.	BENYUS (2002)	GEISSDOERFER ET AL. (2017), LEWANDOWSKI (2016), MACARTHUR (2015), SCOTT (2013)
Laws of ecology	They are four: (i) everything is connected to everything Else, (ii) everything must go somewhere, (iii) nature knows best and (iv) there is no such thing as a “free lunch”.	COMMONER (1971)	MACARTHUR (2015).
Performance economy	It enables entrepreneurs to achieve a higher competitiveness with greatly reduced resource consumption and without an externalization of the costs of waste and of risk.	STAHEL (2010)	GEISSDOERFER ET AL. (2017); LEWANDOWSKI (2016), MACARTHUR (2015), SCOTT (2013).
Blue economy	The need to find a way of meeting the basic needs of the planet and all its inhabitants with what the Earth.	PAULI (2010)	GEISSDOERFER ET AL. (2017); LEWANDOWSKI (2016), MACARTHUR (2015), SCOTT (2013).
Regenerative design	This means replacing the current linear system of transfer flows with cyclical flows at sources, consumption centers and sinks.	LYLE (1996)	GEISSDOERFER ET AL. (2017); LEWANDOWSKI (2016), MACARTHUR (2015), SCOTT (2013).
Permaculture	It is an integrated evolutionary system of perennial or self-perpetuating plant and animal species useful to man, it is a complete agricultural ecosystem.	MOLLISON AND HOLMGREN (1978)	LEWANDOWSKI (2016), MACARTHUR (2013),
Natural capitalism	An approach that protects the biosphere and improves profits and competitiveness. Some changes in how to run the business, based on advanced techniques to make resources more productive, can yield amazing benefits for both current and future generations.	LOVINS, LOVINS, AND HAWKEN (1999)	LEWANDOWSKI (2016), SCOTT (2013).
Industrial metabolism, Industrial symbiosis and Ecoparks	The use of matter and energy in the economic system shows certain parallels with the use of matter and energy by biological organisms and ecosystems. Industrial symbiosis is a merger of two or more different industries, where each industry tries to find optimal access to material components and material elements.	AYRES (1989); RENNER (1947)	GEISSDOERFER ET AL. (2017), LEWANDOWSKI (2016), SCOTT (2013).

With so wide a range of theoretical influences from different epistemological fields such as economy, biology, and environment, it is hard to achieve a consensus about what CE really is. This is what motivates this study.

6.3 Research Methods

The research design combines quantitative and qualitative strategies. It merges bibliometrics, semantic and content analysis because these methods are complementary (CARVALHO, FLEURY; LOPES, 2013). Owing to the great number of academic publications, bibliometric studies are being more accepted and bibliometrics is being recognized as a systematic and relevant approach (IKPAAHHINDII, 1985; NEELY, 2005). The content analysis allows an in-depth understanding of the research constructs and their relationship (DURIAU et al., 2007), while the semantic analysis can help in establishing definitions and narrative scenarios (CARVALHO, FLEURY; LOPES, 2013). The aim is to outline major lines of research in the field, as well as to trigger further research (SEURING; MÜLLER, 2008).

Aligned with the research objectives of mapping the literature on circular economy, a systematic literature review (SLR) approach was selected to answer the three research questions (RQs) as highlighted in the introduction section. The whole research flow is presented in Figure 1.

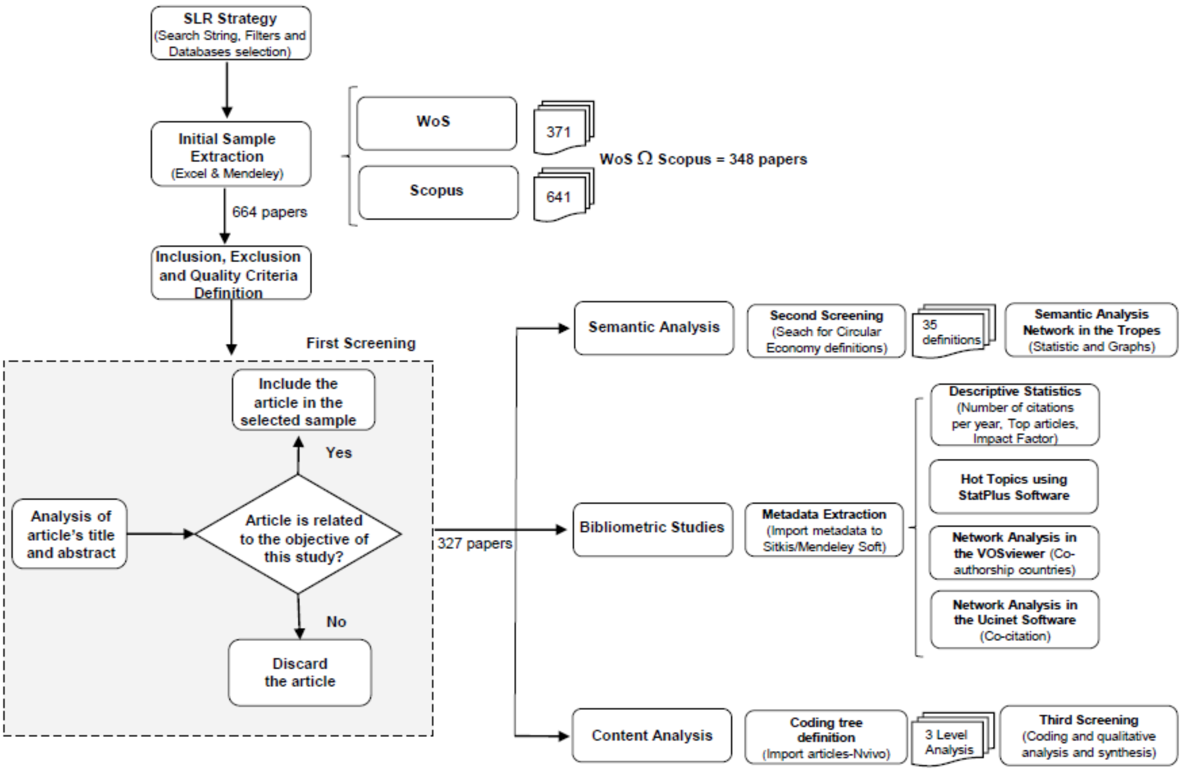

Figure 5: Systematic literature review workflow

6.3.1 Sampling procedures

Data was obtained from the scientific databases, ISI Web of Knowledge, Web of Science Core Collection and Scopus, by late December 2016. The selection criteria for these databases were the quality and quantity of publications; thus ISI Web of Science was selected because it can reach all indexed journals with a calculated impact factor in the JCR (Journal Citation Report) (CARVALHO, FLEURY; LOPES, 2013) and Scopus was selected because it is the largest database of peer-reviewed literature (MORIOKA; CARVALHO, 2016). In addition, both databases provide compatible metadata for bibliometric analysis software, carrying the articles' respective abstracts, references, citation indexes, authors, institutions, countries, among others (CARVALHO, FLEURY; LOPES, 2013).

The only filter applied was "type of documents", choosing only "articles", "reviews" and "articles in press" (the last one only in the Scopus database) because of the robustness of the pairwise review process (TAKEY; CARVALHO, 2016). The search string used was "circular economy", applied as a "topic" in Web of Science, and in Scopus the same search string was applied for "article title, abstract and keyword". 371 articles in the ISI Web of Science (WoS) and 641 articles in Scopus were found. Within this amount, 348 articles were duplicated (found on both databases). The initial sample analyzed was composed of 664 articles (371 WoS + 641 Scopus – 348 WoS Ω Scopus); these were then imported to Mendeley software (Butros and Taylor, 2010) for the first screening based on the analysis of the titles and abstracts. In the screening process, the researchers analyzed each selected publication separately to assess its compliance with the paper selection criteria based on the publication focus and its fit with the research questions, and quality criteria related to the methodological quality of the publications, as suggested in the literature (CARVALHO, FLEURY; LOPES, 2013).. An article was excluded by the researchers' consensus; if agreement was not unanimous, the article remained in the sample for further analysis. The first screening process resulted in a refined sample of 327 articles.

6.3.2 Data analysis

To manage the sample, Mendeley software (BUTROS; TAYLOR 2010) was used, and the Microsoft Access database allowed the metadata generated by Sitkis software to perform further analysis. To answer the three research questions (RQs), three methods were used in the SLR as shown Table 2.

Table 2: Research questions and methods

#	Research Question	Method	Software
1	What are the main research streams, the core topics, authors, and journals?	Bibliometrics and Network Analysis	Sitkis, Access, Ucinet, NetDraw, Minitab, Excel VOSViewer
2	What is the definition of circular economy?	Semantic Analysis	Tropes
3	What is most up-to-date thinking, trends and gaps in the literature?	Content Analysis	NVIVO

First, to answer RQ#1, bibliometrics and network analysis were applied. Three types of social networks were designed: keywords, article to references and co-citations. Sitkis software version 2.0 (SCHILDT, 2006) was used to perform the relational matrix, relating to the metadata of the selected sample, the Excel, Access and Ucinet for Windows 6.289 program(BORGATTI, EVERETT AND FREEMAN, 2002) to encode the relationships and NetDraw to illustrate the relationship diagrams. Furthermore, an overview of the evolution of publications per year, main journals, and authors in this research field is presented, based on descriptive statistics of the general sample, applying additional software, such as Minitab 17 (MINITAB, 2014), and for country analysis the VOSViewer (ECK; WALTMAN, 2010).

The semantic analysis (CARVALHO, FLEURY; LOPES, 2013; WANG; TSAI, 2009) was applied to answer RQ#2. The selected sample was screened for identifying definitions of "circular economy" and the main cited references for definitions such as that from the Ellen MacArthur Foundation were identified and analyzed as detailed in Appendix A. Semantic analysis involves analyzing syntactic structures and textual context in a selected sample (Wang and Tsai, 2009), thus, just definitions in the English language were analyzed, applying Tropes v.8 software (Molete and Landre, 2010).

The content analysis was used for answering RQ#3, based on an in-depth analysis of the core papers (MAYRING, 2014; SEURING; MÜLLER, 2008; TRANFIELD, DENYER ; SMART, 2003). The core papers are defined by the combined analysis of the outliers, i.e., the papers that have the average citation higher than the expected spread in boxplot analysis (see Figure 4), and the impact factor (Equation 1). According to Seuring and Müller (2008), the content analysis may be oriented by a deductive or an inductive approach. The content analysis research protocol combines the recommendations of Tranfiled et al. (2003) and Duriau et al. (2007) in the following steps: (i) planning the review (research questions, search strategy and coding), (ii) conducting the review (frequency counts and cross-tabulations), and (iii) reporting and disseminating (interpretation of results). The NVivo software (BAZELEY; JACKSON, 2013) was used to help the coding process of the sample. The codes tree applied in the content analysis is presented in Table 3.

Table 3: Content analysis codes tree

Research Method	TBL	CE Approach	Main Issues
Conceptual Research			
Literature Review	Environmental	Slowing the Loop	Symbiosis
Simulation or Theoretical Modeling	Economic	Closing the Loop	Trasactional Costs
Empirical Research	Social	Narrowing the Loop	Externalities
Survey	Environ+Economic		Partnership/Alliance
Case Study	Environ+Economic+Social		

For the research methods analysis, the codes tree was defined as suggested by Carvalho, Fleury and Lopes (2013), applying a mix of deductive approach based on the theoretical background and insights of bibliometrics. This paper uses insights extracted from the keywords and the hot topics analysis. First, the triple bottom line (TBL) codes, as proposed by Elkington (1997), were applied to each paper according to one perspective (environment, social or economic) or a combination of them. Second, the codes for the circular economy approach included three main loops as follows: slowing (STAHEL, 1994; STAHEL, 1997), closing (MCDONOUGH; BRAUNGART, 2010) and narrowing material flow (BRAUNGART et al., 2008; BOCKEN et al., 2016). Slowing the resource loop, according to Stahel (1994), would be the extension of a product's life. McDonough and Braungart (2010) explain the closing of a loop as the ideas of post-use and recycling. Narrowing the resource loop as suggested by Braungart et al. (2008) would be through a more efficient use of environmental resources. Bocken et al. (2016) also discuss the necessity of using the three approaches in a balanced way to implement a real circular economy.

Third, the industrial ecology and symbiosis codes were deployed as follows: transaction costs (SU et al., 2013; HSU, 2013), symbiosis (CHERTOW, 2000; LI, DONG; REN, 2015), externalities (DAHLMAN, 1979), and partnership and alliance (BARBER, BEACH; ZOLKIEWSKI, 2012). Transaction costs refer to the organizational attempt to minimize the internal costs of managing exchanges, and the costs of exchanging resources in the environment (CHOI; KRAUSE, 2006). According to Chertow (2000), industrial symbiosis consists of physical exchanges among different entities of "materials, energy, water, and by-products". The externalities concept (DAHLMAN, 1979) adopted in this analysis is the consequence of an economic activity, production or consumption of a specific good, having an impact on a third party that is not directly related to the production or consumption of that good: pollution, for instance. The idea of partnership and alliance adopted in the study is the interaction between organizations cooperating to reduce waste and energy use in developing and implementing a product, and also in pollution preventive processes (VACHON; KLASSEN, 2006)

6.4 Results

6.4.1 Literature panorama: evolution, core journals, authors and topics

An initial literature overview based on descriptive statistics of the sample was performed. Pareto chart was applied to show the yearly contribution. It is a bar chart in which the horizontal axis represents attributes of interest, in our case years, by ordering the bars from the largest to the smallest occurrence, and a cumulative percentage line helps to judge the added contribution of each category (year). Figure 2 shows the yearly evolution of circular economy publications, highlighting that 73% of the sample was published in the last three years (2014-2016), and the number of publications has more than doubled yearly since 2013, showing a very rapid increase of interest in this subject in recent years. The oldest publications found in WoS were published in 2006 and in Scopus in 2001.

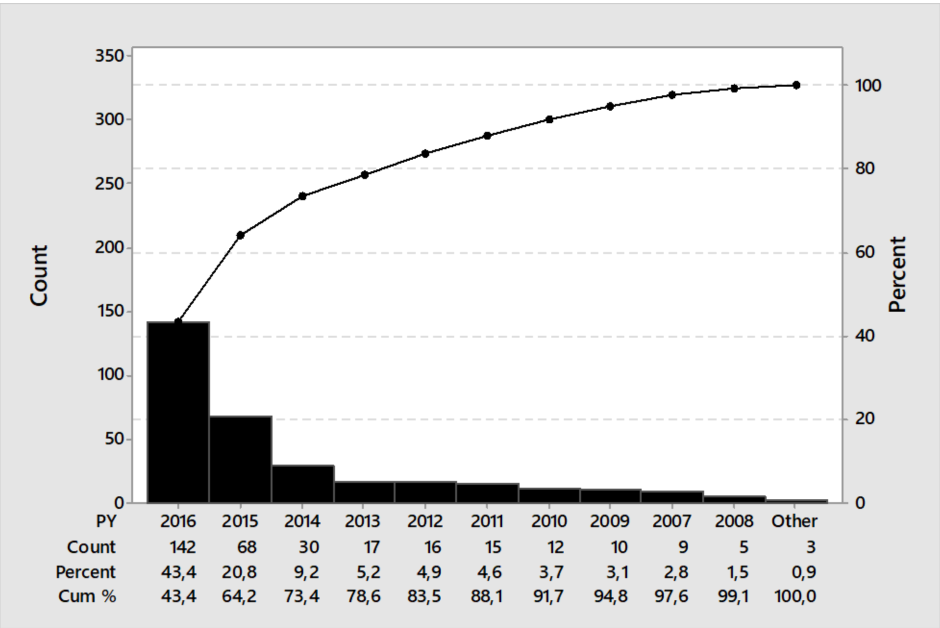

Figure 2: Year Pareto chart for CE publications

The six journals that most published papers on CE represent 44% of the total sample. The first of these is *The Journal of Cleaner Production*, which is the main source of publications on CE (75 papers) and has the most varied scope on the topic, having more technical papers on recycling and other related issues towards sustainable business models. The second is *Resources Conservation and Recycling* (20 papers), which has a diverse content of subjects linked with CE. *The Sustainability Journal* is the third with 19 papers, mostly regarding ecoparks and industrial symbioses discussions on the supply chain. The fourth is the

Journal of Industrial Ecology (14 papers), in which the most frequent themes are the operational and strategic level, aligned to business education reflections, strategic niches approaches, low carbon city strategies, infrastructure and sustainable business models. The last two journals are *Waste Management* (8 papers) and *Bioresource Technology* (7 papers).

The sample core papers were identified from the citation and co-citation analysis, a quantitative technique applied to capture the impact and relevance of either an author or an article (Garfield and Merton, 1979). However, this evaluation should also consider the journal impact, in addition to counting the total citation or yearly average citation, because it “can change the position of one paper in the ranking of citations” (Carvalho, Fleury and Lopes, 2013), as shown in Equation 1.

AIF= Yearly average citation * (1+JCRIF) (Equation 1)

Equation 1 drives the further analysis for defining the core papers, using both yearly citation and journal relevance in the analysis. The impact factor and citations likely change over the years, however, since we used the average citation, the result obtained is less sensible to yearly variations then the one obtained by the use of total citations. Table 4 highlights the top articles considering the combined impact factor as proxy of relevance in the circular economy sample, emphasizing their research themes and journals.

Table 4: List of the most cited papers

Authors	Article Title	Journal	Average Citations	JCR/ IF*	AIF
PETERS,WEBER, GUAN, HUBACEK	China's growing CO(2) emissions - a race between increasing consumption and efficiency gains	Environmental Science & Technology	23.91	6.198	172.1042
HUANG, GUO, XU	Recycling of waste printed circuit boards: A review of current technologies and treatment status in China	Journal of Hazardous Materials	21.33	6.065	150.6965
MIRABELLA, CASTELLANI, SALA	Current options for the valorization of food manufacturing waste: a review	Journal of Cleaner Production	24.00	5.715	161.1600
SHI, CHERTOW, SONG	Developing country experience with eco-industrial parks: a case study of the Tianjin economic-technological development area in China	Journal of Cleaner Production	13.88	5.715	93.2042
ZHANG, DING, ZHANG, CHEN, DING, VAN LOOSDRECHT, ZENG	Fatty acids production from hydrogen and carbon dioxide by mixed culture in the membrane biofilm reactor	Water Research	7.40	6.942	58.7708
CHERTOW, EHRENFELD	Organizing self-organizing systems	Journal of Industrial Ecology	14.67	4.123	75.1544
GENG, FU, SARKIS, XUE	Towards a national circular economy indicator system in China: an evaluation and critical analysis	Journal of Cleaner Production	13.00	5.715	87.2950
XI, GENG, CHEN, ZHANG, WANG, XUE, DONG, LIU, REN, FUJITA, ZHU	Contributing to local policy making on GHG emission reduction through inventorying and attribution: a case study of Shenyang, China	Energy Policy	7.86	4.141	40.4083
ZHANG, YUAN, BI, ZHANG, LIU	Eco-industrial parks: national pilot practices in China	Journal of Cleaner Production	7.12	5.715	47.8108

Note: Papers in descending order of article impact factor (AIF).* JCR/IF (2016).

Figure 3 presents the performance of the core papers in a boxplot chart, emphasizing how outlier is each one of the top articles. The identified citation values represent papers from the sample whose article impact indexes are extreme outliers (asterisks), performing more than 7 citations. It evidences also the medium outliers (dots), of which citation values vary between 5 and 7, considering the impact factor. In view of the impact factor of the *Journal of Cleaner Production*, for instance, the paper from Mirabella, Castellani, and Sala (2014), about food manufacturing waste, becomes the third in the total ranking instead of the eighth position regarding only the total citation. It is possible to observe also that most of the high impact factor papers are related to the Chinese perspective. An in-depth discussion of these papers is performed in the next sections.

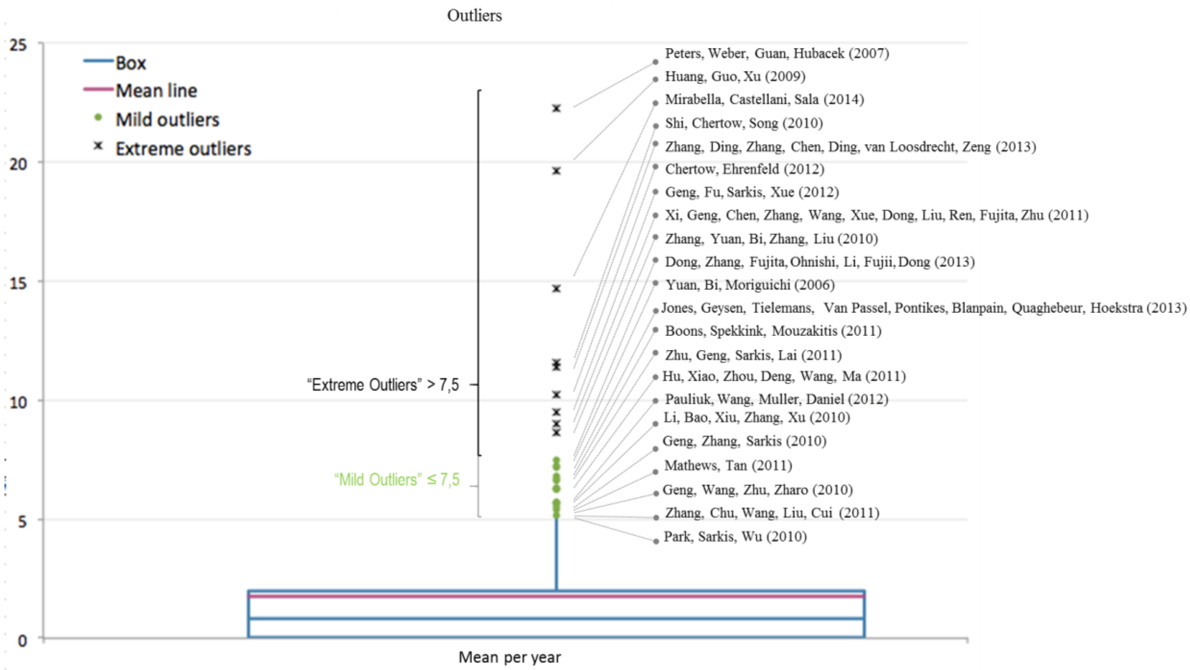

Figure 3: Articles outliers in number of citations from the CE sample

*Note: Papers in descending order of citations

6.4.2 Research streams

To understand the research collaboration on CE, the first network performed was the country co-authorship, performed with the software VosViewer version 1.6.1 (Eck and Waltman, 2010). Figure 4 shows the relationship between countries.

The countries co-authorship network is composed of six clusters. The main cluster in terms of number of publications groups Australia, Austria, Italy, USA and England. The China, Japan and Canada cluster draws attention because of the high amount of Chinese studies. Finland, Germany, Denmark and Sweden form another grouping, and finally Belgium, Netherlands and Greece. The cluster grouping China, Japan and Canada highlights the great co-relationship between China and Japan, which have similar circular economy policies, focused on avoiding environmental damage and on natural resources conservation through integrated solutions for solid waste management (SU et al., 2013). It should be noted that only two papers of the total CE sample were effectively published in China, even though 40% of the authors are Chinese.

The CE approach in developing and developed countries should also be noted. The European Union has been developing a circular economy since 1995, by exploring and managing waste through treatment centers and recycling resources (CUCCHIELLA et al., 2015). Here there is a more consolidated CE policy, in which resources conservation and "zero waste" is set as a goal (MANARA; ZABANIOTOU, 2016). To achieve this, the co-authorship networks evidence the search for partnerships between European countries. On the other hand, the central government of China guaranteed in 2002 to stimulate the sustainable development of economy and society (YUAN, BI; MORIGUICHI, 2006). This has been led by technology innovation and capabilities creation at enterprise and mainly industrial zone level.

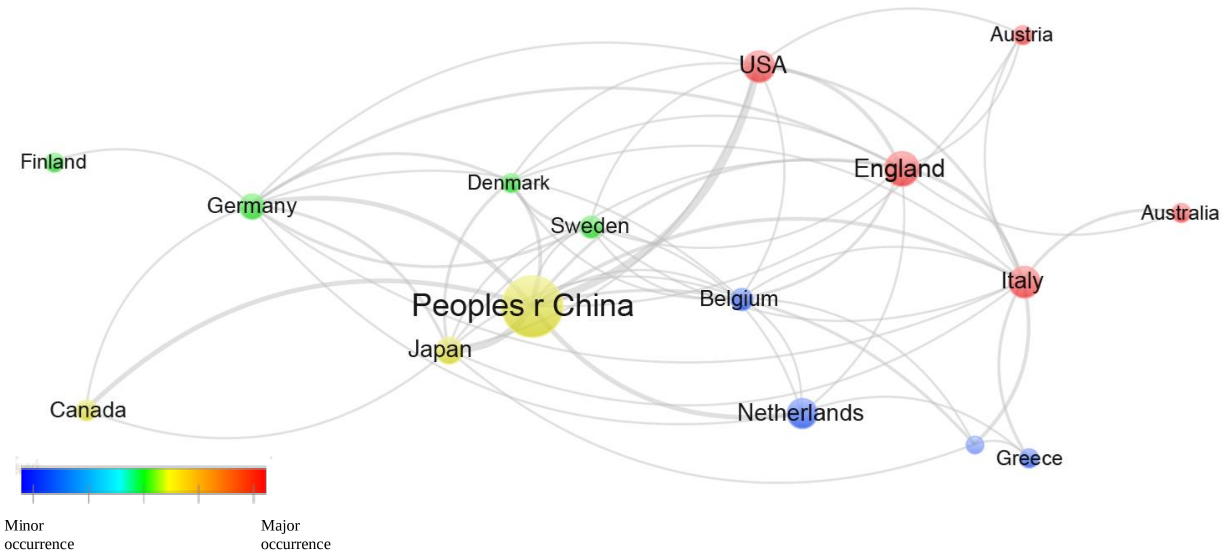

Figure 4: Countries co-authorship for the circular economy sample. Note: This network was performed with threshold criteria of at least five articles co-authorship by VosViewer software using extracted data from the ISI and Scopus database. The size of the symbols corresponds to the number of publications citations and the color corresponds to the number of co-authorship occurrences in publications.

The second analysis was performed using the co-citation network (Figure 5) that illustrates the relationship between articles (PILKINGTON; LISTON-HEYES, 1999; PILKINGTON; MEREDITH, 2009), clarifying the intellectual structure (CULNAN; O'REILLY, 1990) and the research field connections (BELLIS, 2009). The thicker the line linking two co-cited articles, the more frequent the co-citation is, indicating the relatedness of their research (YU, DIJKEMA ; DE JONG, 2014). The co-citation network brings together both the publications from the selected sample and also the references of this publications that do not belong to the sample, but that are always cited together in those publications (PILKINGTON; MEREDITH, 2009). This network presents the big picture of the research area, meaning that the more the publications are cited together, the more likely they are to delineate a "school of thought" (CULNAN; O'REILLY, 1990). In this case, Figure 5 represents the most relevant literature cited together in the circular economy research area.

Figure shows the co-cited articles from the circular economy sample that are clustered into four main groups: circular economy principles, symbiosis, ecoparks and supply issues. In this network, papers on circular economy principles mainly discuss concepts and case studies such as: Zhu, Lowe and Barnes (2007); Li et al. (2010), while the implementation and benefits for countries and investors are concentrated in ecopark publications, such as the papers from Geng et al. (2009); Shi, Chertow and Song (2010);Yuan, Bi and Moriguichi (2006a), Gibbs and Deutz (2007); Van Berkel et al. (2009). The need for circular economy in the supply area is another issue discussed in publications such as: Geng and Doberstein (2008); Geng, Zhu et al. (2009); Murphy and Gouldson (2000); Liu and Anbumozhi (2009) as well as business strategies to improve industrial economy and environmental performance by industrial symbiosis, such as Chertow (2000); Chertow and Lombardi (2005); Chertow (2007); Geng, Tsuyoshi and Chen (2010).

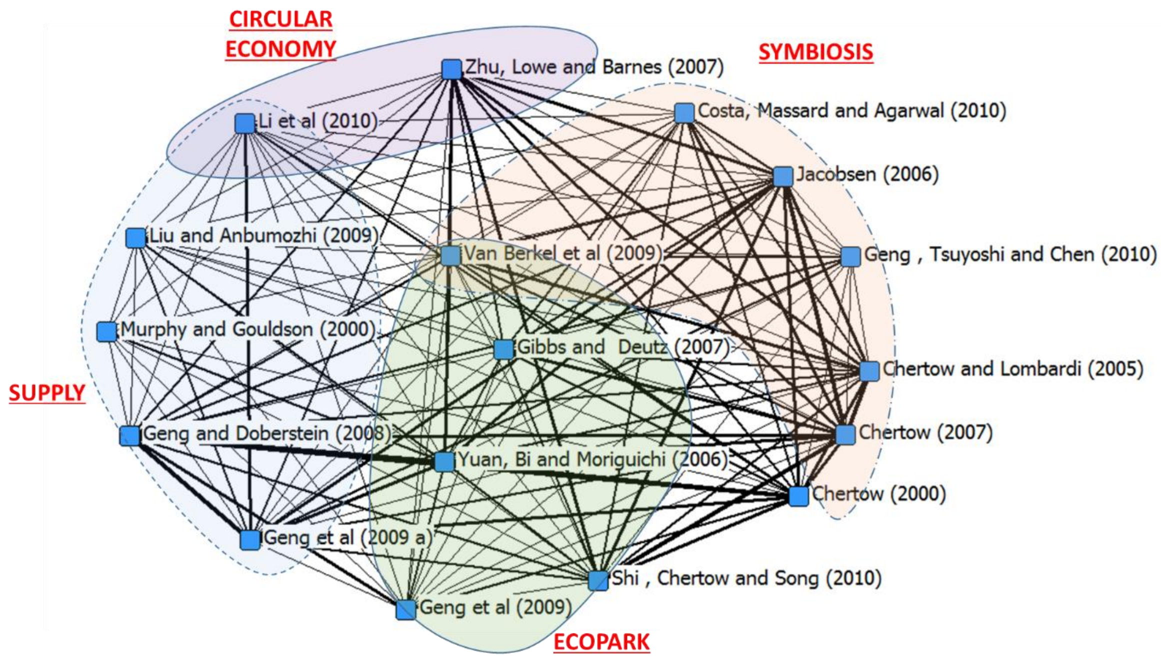

Figure 5: Co-citation network for CE. Note: This network was created with Ucinet software using the metadata encoded by Sitkis software (filter criteria: at least seven citations per cited and citing reference) The strength of ties corresponds to the intensity of relationships.

6.4.3 Research topics and trends

In order to identify hot topics or compounds related to studies on circular economy, initially a scan was performed on the selected sample of 327 articles, using NVivo software (BAZELEY; JACKSON, 2013). This evaluation investigated the distribution and frequency of words on article titles, author keywords, abstracts and KeyWords Plus to obtain the most promising research topics and future trends. This led to a list of 24 recurrent topics or compounds, based on the software outputs (Figure 6), meaning that "carbon emissions" is less frequently mentioned than the word “development”.

To perform the “hot topics” analysis, a complementary analysis was undertaken, combining the recurring topics from Figure 6, which provided the HB index (HIRSCH, 2005). Using research by Banks (2006), index M from Figure 6 was calculated in this paper as a linear mathematical relationship between h-b and the number of years n (n= 11 years), elapsed since the first publication (in this case, 2006), including the topic or compound, Equation2.

$$HB \sim M*n \qquad (2)$$

The criteria for the interpretation of the M index are presented in Figure 6, according to Banks' criteria (2006). In this sample, the “carbon emissions” issue is not yet a hot topic within circular economy; however, themes of “supply” and “supply chain” are at the lower end of being considered hot topics. This may represent a gap in research to be explored (circular economy and the supply chain). Words such as “industrial”, “China”, “products” already appear as known issues within circular economy.

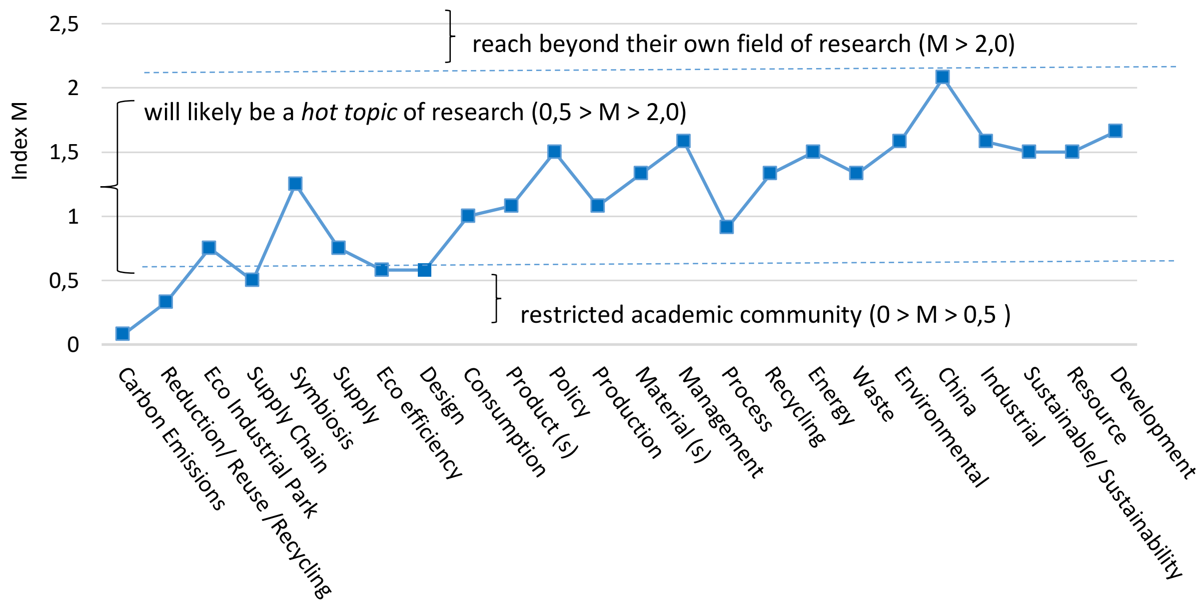

Figure 6: Hot topics in percentage from the CE sample

To complement the overview on the selected sample (327 papers), the circular economy keywords network is presented in Figure . These words were categorized into 4 main groups: (1) strategic variable, that corresponds to the main drive to circular economy (sustainable development); (2) operational variables, corresponding to the path that can be used to reach circular economy (design, model, system(s), management, waste management, performance and challenges), (3) inputs that are the independent variables within the circular economy research theme (Chine, industry, environment, energy, ecology) and (4) outputs, that are the result of the circular economy implementation (recycling, symbiosis, reuse, industrial symbiosis, sustainability, industrial ecology, waste, emission, eco-efficiency).

The strength of the ties connecting the nodes illustrates the intensity of the relationships of the keywords mentioned together in the sample (CARVALHO, FLEURY; LOPES, 2013). The filter criteria for this diagram were set at a minimum of ten occurrences for each keyword. The main connections revealed are the ones between CE and management (or waste management), CE and sustainable development, CE and industrial symbiosis and ecology. There is also an outstanding connection between CE and China, owing to the number of publications about Chinese cases, mostly related to Industrial Ecology and Eco-Industrial Parks. Further support for understanding these relationships was obtained from the content analysis.

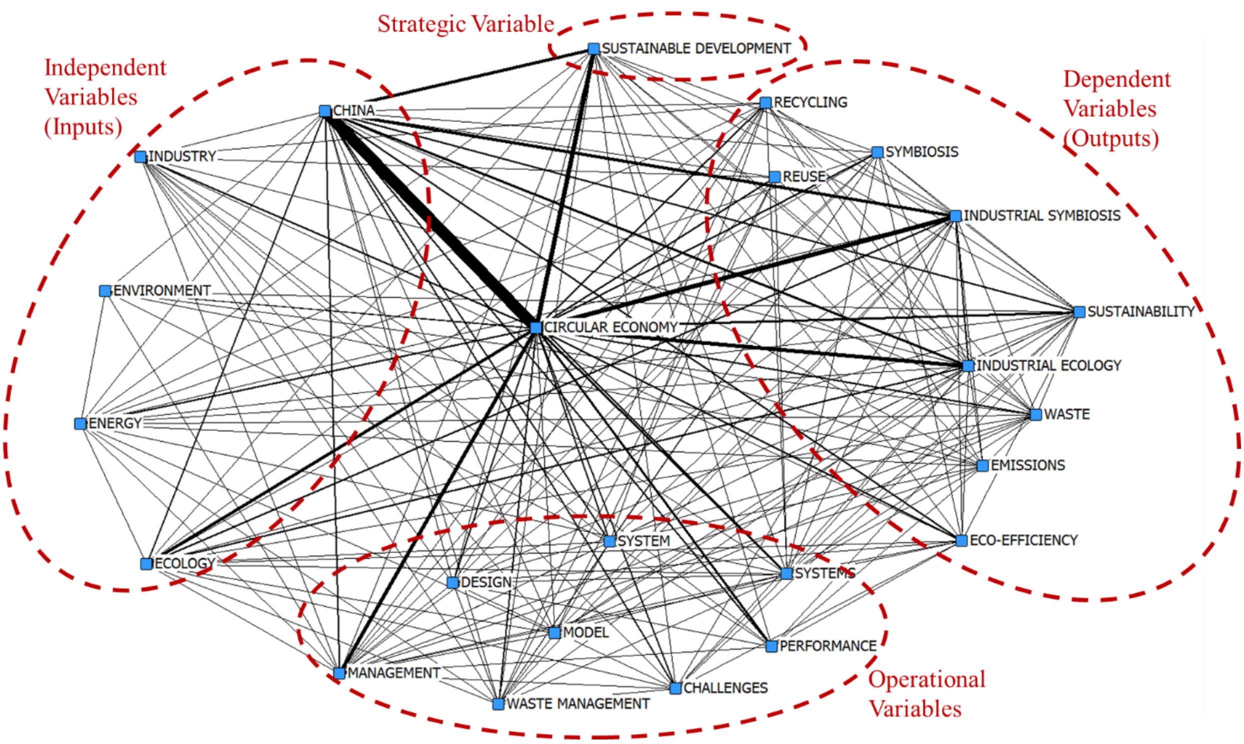

Figure 7: Keywords network from the CE sample. Note: This network was performed by Ucinet software using extracted data from Sitkis software. The strength of ties correspond to the intensity of relationships (a minimum of ten occurrences). On the left the main inputs (independent variables), on the right the main outputs (dependent variables), in the bottom the operational variables, in the top the strategic variables.

6.4.4 Circular economy definitions analysis

Since circular economy is an emerging topic and the term still lacks a structured definition, a semantic analysis was performed in order to gain a better understanding of its meaning within the related literature. This method involves an analysis of syntactic structures and textual context in a selected sample (WANG; TSAI, 2009). For this procedure, the authors searched for CE definitions in the sample of papers, in which 35 definitions were selected (Appendix A). A detailed analysis of the definitions was realized with the support of the software Tropes, and a more comprehensive "CE sample-based" definition was shaped. The results are detailed in Table 5 and Figure 9.

The words most closely connected (Table 5) are "circular economy" and "resource", and "resource" and "productivity", evidencing the eco-efficiency theme in the papers. Other frequent word connections are "waste", "energy" and "equipment". Figure 8 presents the connections (actant/acted straightness) between words from the definitions of circular economy.

Regarding the software analysis results (Figure 8), the outlined area in the chart represents the location of the term "supply chain" in the CE context. Based on the Tropes statistics report and the whole research process (Table 5 and Figure 8), one important output is that the link between "supply chain" and "circular economy" is weakly established in the studied definitions, and this needs further analysis.

In the research stream analysis, based on the bibliometrics, it was possible to identify a cluster related to "supply", but it does not stood out in the semantic analysis. Thus, despite some studies exploring opportunities in circular supply chains for renewable chemical feedstock (TSOLAKIS; KUMAR; SRAI, 2016); network reconfiguration (SRAI et al., 2017) and sustainable supply chain management towards a circular economy (GENOVESE et al., 2017), these are not yet the core subject in circular economy definitions.

Table 5: Tropes statistics report

Main themes*	Frequency	Main themes*	Frequency	Relations (Tightly connected*)	Frequency
circular economy	39	model	4	(circular economy > resource)	7
resource	27	productivity	4	(resource > productivity)	6
equipment	16	consumption	4	(resource > eco efficiency)	4
economy	13	part	3	(waste > resource)	4
product	12	life	3	(equipment > energy)	4
development	7	closedloop	3	(circular economy > equipment)	4
way	7	cycle	3	(productivity > eco efficiency)	4
waste	7	sustainable development	3	(circular economy > sustainable development)	3
value	7	market	3	(circular economy > closed loop)	3
environment	6	supply chain	3	(product > design)	3
energy	6	improvement	3	(circular economy > strategy)	3
use	6	procedure	3	(strategy > resource)	3
management	6	concept	3	(use > resource)	3
strategy	5	production	3	(closedloop > s)	3
industry	5	scarcity	3	(resource > improvement)	3
china	4	aim	3	(way > resource)	3
design	4			(development > resource)	3
system	4			(circular economy > development)	3
eco efficiency	4			(resource > scarcity)	3

*At least three times

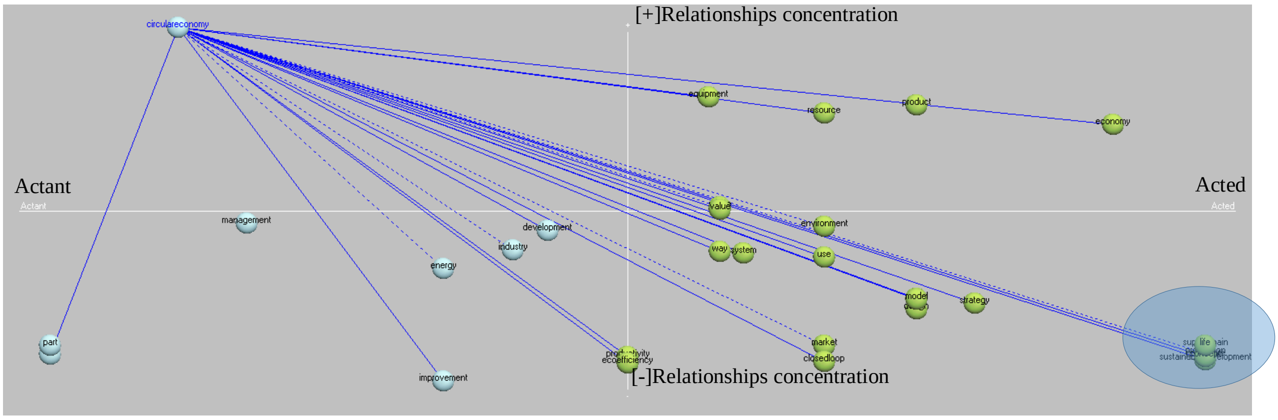

Figure 8: Example of an actor's graph linked to the definitions of circular economy (origin of all conexions). Note: The X axis (horizontal) shows the actant/acted ratio (from left to right). The Y axis (vertical) shows the relationships concentration for each reference displayed (strong at the top of the graph, weak at the bottom). The lines show the relationships between the references.

Some authors argue that circular economy as an alternative model to traditional linear economy (GREGSON, CRANG, FULLER; HOLMES, 2015), needs to be treated in a holistic manner (JIAO; BOONS, 2014). As a synthesis of the sample definitions analyzed established that the most recurrent phrases lead to CE being: a new strategy (SU, HESHMATI, GENG; YU, 2013) or a path (ZHANG et al. 2009) for promoting sustainable development, reducing environmental harm and facing the challenge of resource scarcity (YUAN, JIANG; LIU, 2008). It is important to note that social aspects are neglected as part of the sustainable development goals in most definitions; whereas the link between economic and environmental issues is stressed in several papers. CE aims to improve efficiency in materials and energy (HU et al., 2011; GENG;DOBERSTEIN, 2008), through a minimized input of virgin materials and reduced outputs of waste (HAAS, KRAUSMANN, WIEDENHOFER; HEINZ, 2015), and closed loops of reuse and recycle (PETERS, WEBER, GUAN;HUBACEK, 2007; JIAO; BOONS, 2014). Some authors also mention that the change to a circular economy also demands changes in product design, manufacturing and supply chain management approaches (SMOL et al., 2015; WEI et al., 2014).

Based on the results of the analysis, a definition is proposed: *CE is a strategy that emerges to oppose the traditional open-ended system, aiming to face the challenge of resource scarcity and waste disposal in a win-win approach with economic and value perspective*. The circular aspect of this concept is core, based on the understanding of the several possible biological and technical loops, which differs from other sustainable development approaches. Since circular economy is based on principles such as lifecycle extension, sharing, reuse, recycling, remanufacturing and refurbishing, its feasible implementation depends on rethinking operations management, particularly products and services lifecycles (beginning of life – BOL, middle of life – MOL, and end of life – EOL), manufacturing processes and supply chain management activities.

6.4.5 Content Analysis

The overall results of the content analysis based on the codes tree is presented in Figure 9. The selection criteria to perform this step was to address the supply chain perspective, since this field presents one of the weakest links identified by the semantic analysis. It should be also noted that to operationalize properly the next steps towards circular economy, the whole supply chain needs to adapt (SRAI et al. 2017; TSOLAKIS, KUMAR; SRAI 2016). Thus, the most relevant papers linking supply chain and circular economy were selected gathering a core sample of 39 papers.

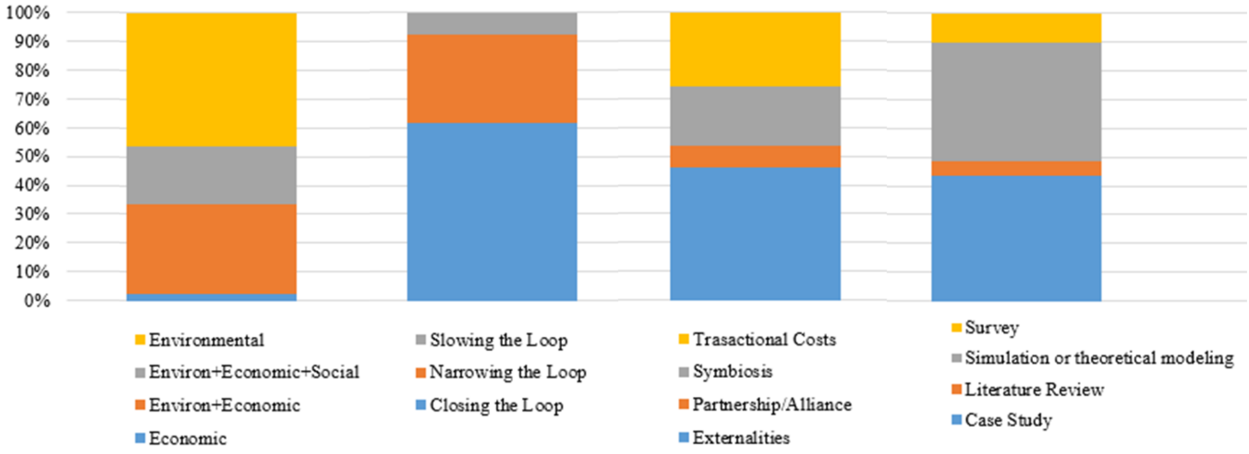

Figure 9. Summary of the content analysis

It can be noted that most papers discuss closing the loop (63%) and externalities (35%). Regarding the research methods applied, the case study (46%) is the most often used. Still, just a few papers discuss CE from a triple bottom line perspective (19%).

The content analysis applying the triple bottom line codes (see Figure 10), allows the evolution of the TBL (social, environmental and economic) pillars over time. Environmental and economic issues are the most frequent, while concern with social issues emerges in papers, suggesting integrated policies and regulation implementation impact directly on people's wellbeing in industrial areas such as the paper of Boons, Spekkink and Mouzakitis (2011) and Geng, Mitchell and Zhu (2009). Regarding these social aspects, to increase circular economy effectiveness, it is essential to consider "what collaborative efforts or policy intervention would be relevant"(DIENER; TILLMAN, 2016).

The recent British Standard Framework to CE (BS 8001:2017) is one example of the many efforts towards scaling up the circular economy implementation. Many companies, universities and governmental agencies were involved in the development of this practical implementation guide based in six main principles: systems thinking; innovation; stewardship; collaboration; value optimization and transparency (BS, 2017), concentrating on the move from the old-fashioned and polluting linear economy to the innovative and sustainable CE.

Besides that, Table 6 presents the most relevant papers that explicitly mention the importance of policies and regulation to leverage the CE implementation.

Table 6: Most relevant papers mentioning the impact of policies and regulations towards the implementation of CE

Authors	Times Cited	Subject
PETERS ET. AL, 2007	263	The paper discusses and analyzes the growth of energy consumption and CO2 emissions in China, as well as the application of public policy developments to try to reduce this problem.
GENG AND DOBERSTEIN, P. 1, 2008	85	As explained by the authors: "The paper describes current measures being implemented in China for the long-term promotion of a circular economy, including the formulation of objectives, legislation, policies and measures, so that the country can 'leapfrog' its way from environmentally damaging development to a more sustainable path.
GENG ET. AL, 2012	77	The article discusses China's rapid economic growth and its negative effects on the environment. The authors wrote that CE has been chosen as a national policy for sustainable development, to implement the national laws and regulations have been enacted to facilitate the implementation.
SU ET. AL, 2013	69	The article discusses CE in China and how this legalization, accepted since 2002, helps to improve the efficient use of raw materials and preserving the environment.
ZHANG ET. AL, 2010	57	The rapid development of eco parks in china and the involvement of government agencies are discussed in this article.
ZHU ET. AL, 2011	57	China's supply chain has been under regulatory pressure to implement sustainable practices.
ZHANG ET. AL, 2011	51	The large number of vehicles of china and the lack of material to continue the production, raise new concern for the Chinese government. The automotive remanufacturing industry in China is only at the preliminary stage, and encounters some barriers, including policies and regulations.
DONG ET. AL, 2013	44	The importance and benefits of industrial symbiosis (IS) formation in China are addressed in this paper. Among other points, legislative framework and support policy, are needed to support the ever-improving IS promotion in China's iron / steel industry.
GENG ET. AL, 2010	41	The article discusses the main initiatives for cleaner production in China and comments that regional governments have played a leading role in promoting it.
LI ET. AL, 2010	39	Policies and programs of Chinese government related to energy conservation were introduced in combination with China's circular economy structure, to solve environmental problems in China.

Positives impacts can also be reached by “developing the domestic secondary supply of REE (Rare Earth Element)”, because it can provide societal benefits by supporting regional and national goals towards circular economies (MACHACEK et al., 2015). However, unsustainable production and consumption, especially in industrialized countries, are pointed as great causes of environmental damage (VELEVA et al., 2001).

The CE analysis on the efficiency of supply chain, narrowing the loop (Figure 11) shows that it was initially an important subject related in 12 papers such as: Yuan et al.(2008); Zhu, Geng and Lai (2010); Zhu, Geng and Lai, (2011); Zhu et al. (2011). However, closing the loop began to grow as a goal and 24 papers of this sample present this approach, i.e. Cucchiella et al. (2015);Pan et al. (2014); Tu et al. (2011b). Currently, the extended lifecycle is featured in circular economy discussion, in just three papers of this sample (DALHAMMAR, 2016; POLLARD et al., 2016; VAN WEELDEN, MUGGE; BAKKER, 2016). Figures 11 to 13 show the summary of this analysis.

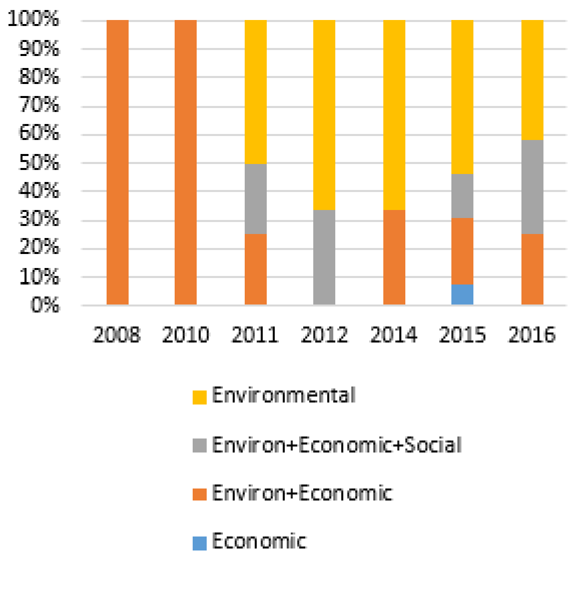

Figure 10: TBL approach yearly evolution

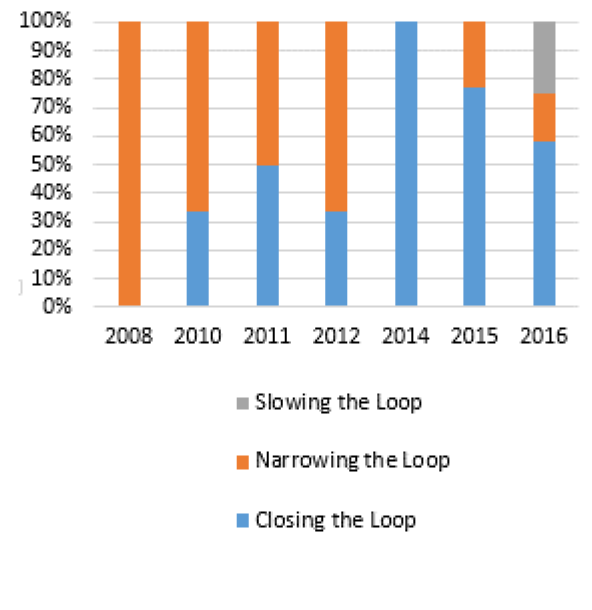

Figure11: Approach evolution over the years

The conceptual analysis is composed of simulation and theoretical modeling and literature review, addressing corporate sustainability (BAI, SARKIS; DOU, 2015) and critical materials for product design (PECK, KANDACHAR;TEMPELMAN, 2015). Only a few surveys were identified in the sample, all of them from the same main author i.e.Zhu et al.(2011); Zhu, Geng, and Lai (2011); Zhu, Geng and Lai (2010b); Zhu, Sarkis and Lai (2012) and only two of them dealing with partnership issues, practices in CE and environmental supply chain cooperation, and performance results. Most papers used quantitative approaches, but a few used qualitative approaches.

Within the eco-supply approach, “green supply chain management has emerged as an important organizational philosophy to reduce environmental risks” (DIABAT; GOVINDAN, 2011). Note that the most cited paper of this sample is a survey about green supply chain evaluation from an ecological modernization perspective paper of Zhu et al. (2011a), which enables an innovative systems solution during the supply chain transition path (POTTING et al., 2016).

As expected, the symbiosis code is relevant, corresponding most to closing and narrowing the loop (Figure 12). The most relevant papers in terms of symbiosis classification are the theoretical modeling on the organizational complexity of ecoparks (CHERTOW; EHRENFELD, 2012), a qualitative case study about the experiences of Tianjin (Shi, Chertow and Song, 2010b) and a framework about the dynamics of industrial symbiosis based on a literature review (BOONS, SPEKKINK;MOUZAKITIS, 2011). They express and prove in different ways that "turning waste into a resource is a way to increase resource use efficiency and close the material loop of a circular economy" (JIMNEZ-RIVERO; GARCIA-NAVARRO, 2017).

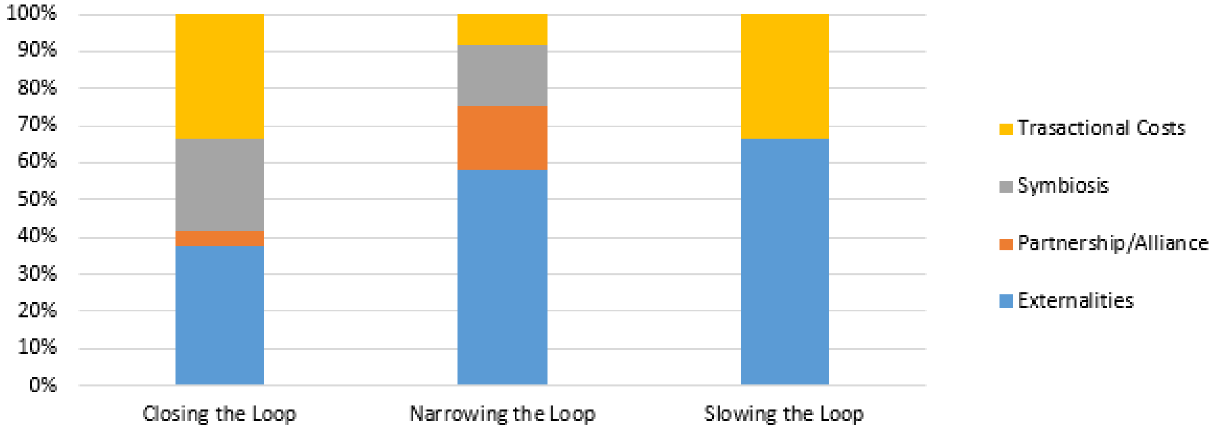

Figure 12: Main themes according to the CE approach

Regarding the partnership and alliance, these terms are mostly in case studies papers (Figure 13), contextualizing pilot practices (ZHANG et al., 2010), process integration (YU, de JONG;DIJKEMA, 2014), evolution of symbiosis approaches (YU, HAN ; CUI, 2015) and the effect of policy instruments (YU, DIJKEMA; DE JONG, 2015). There is only one paper with a theoretical quantitative modeling approach on the perspectives of the development of ecoparks in China, based on past experiences of senior officials from 51 Chinese industrial parks (ZHU et al., 2014). The most cited paper of this sample is a Tianjin economic-technological development area in China (SHI, CHERTOW; SONG, 2010b), a qualitative case study focusing on industrial symbiosis. The symbiosis subject is therefore, closely related to the ecopark concept, followed by partnership issues. Regarding partnership, it should be noted that there is a lack of investigation on how this paradigm can be enabled through inter-organizational cooperation among different business companies (RUGGIERI et al., 2016).

Another interesting point is that transactional costs appear in a quantitative way only in the context of narrowing the loop (eco-efficiency) i.e.Liu et al. (2015); Yong, Geng et al., (2014); Yong, Geng, Mitchell and Zhu (2009). Related to that, to effectively accomplish the goal of circular economy to a great extent, according to Ayres et al. (2013), "major investments in energy efficiency and renewable energy technologies in the near and medium term" are required. The CE solution must encompass “long-run (20–30 years) investors (pension funds, insurance companies) and probably take the form of securitized, resource-based bonds” (AYRES et al., 2013).

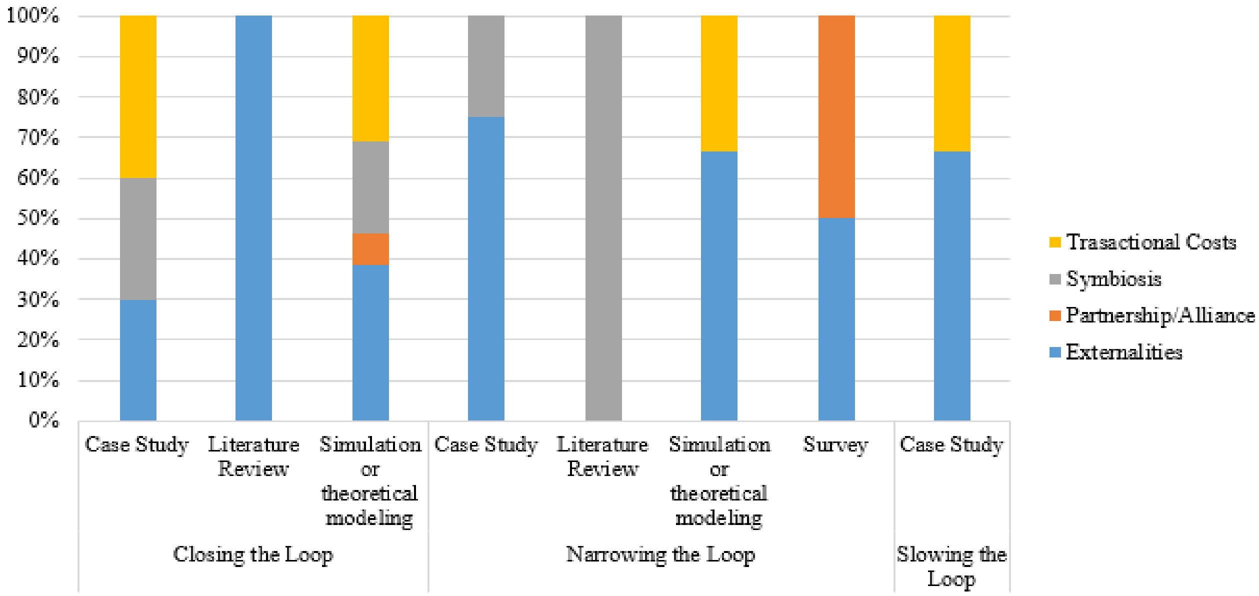

Figure 13: Distribution of research methods according to main issues and CE approach

Chinese case studies are a constant in this sample, followed by theoretical modeling, mainly in using the closing-loop approach. Table 7 presents the most relevant case studies from the sample.

Table 7: Most relevant papers about case studies.

Authors	Times Cited	Subject
SHI ET'AL (2010)	111	A case study of the Tianjin Economic-Technological Development Area, assessing the environmental benefits of the key symbiotic exchanges in TEDA.
GENG ET. AL (2010)	58	The paper provides insight into the environmental performance and sustainability of an industrial park.
XI ET. AL (2011)	54	This paper shows how a clear inventory analysis on GHG emissions at city level can help to identify the major industries and societal sectors for reduction efforts so as to facilitate low-carbon policy-making.
PARK ET. AL (2010)	47	This paper investigates the challenges and opportunities of how firms and organizations can and will be able to strike a better balance between economic growth and environmental stewardship in the context of China's emerging 'circular economy' policy.
YANG AND FENG, (2008)	42	This study expounds on its whole transition course to a circular complex in the past decade, in which four factors are essential to making this symbiosis achievable: rational production structures; raw materials advantages; technical supports and correct diversification.
GENG ET. AL (2010)	41	This paper reflects such a perspective through a case study of Liaoning province.
LIU ET. AL (2009)	40	This study creates a better understanding of public awareness and performance in the promotion of a Circular Economy (CE) in Tianjin, China.
MO ET. AL(2009)	34	This paper characterizes the current recyclable resource recycling system by a detailed field survey carried Out from 2006 to 2008 in Suzhou city.
CHEN ET. AL (2012)	27	By analyzing 88 sample recycling projects in 23 eco-towns in Japan, this article focuses on the factors of project scale, recycling boundary, and types of waste in relationship to environmental benefits and operational performance.
DONG ET. AL (2013)	24	This research shed light on how industrial symbiosis contributes to city's low-carbon development.

For the slowing loop approach, there is still a gap, perhaps because extending a product's life strongly depends on closer implementation by the consumer as well, which may also mean a huge change on cultural consumption patterns (POLLARD et al., 2016; VAN WEELDEN, MUGGE; BAKKER, 2016).

Slowing the loop could also be reached by "using products more intensively; for longer; light weighting products and increasing reuse, at the product and at the component levels" (PAULIUK et al., 2017). As mentioned previously, "legislation, like a business strategy, can be driven by a different perspective of value and alignment with the goals of a circular economy agenda" which encompasses another fundamental pillar to CE deployment (MACHACEK et al., 2015).

6.5 Discussion

Although some previous literature reviews on CE were identified during the analysis process (Appendix B), none have so significant a sample and applied multi-methods analysis. Moreover, none explore together the loops approach, the industrial ecology topics and the TBL perspectives, or specifically address circular economy in the context of material flow and the macro issues of circular economy. The main themes addressed in previous reviews are the industrial symbiosis as unit of analysis and the deployment of specific technical issues.

This systematic literature review confirms, according to Ezzat (2016), that some of the circular economy model dimensions are absent, including "the legislative, institutional and cultural issues". Regarding their influence in social discussion, these missing dimensions are considered to present major challenges to transitioning towards a circular economy model; instead, there remains support for a linear economy (EZZAT, 2016).

Three main clusters within the CE field were identified: symbiosis, ecoparks and supply chain. The overview given by this research, at this point, provides some main results that should be emphasized. General publications on circular economy come mostly from China-related cases, since the mandatory CE regulation was enforced in 2009 (JIAO; BOONS, 2014; YU, DE JONG; DIJKEMA, 2014). These publications are concerning particularly to symbiosis and ecoparks clusters. Nevertheless, the growing number of publications, as evidenced by the yearly evolution of publications, show different pathways to the circular economy development indicating new trends.

To amplify the insights on the supply cluster, a specific additional research filter was performed, based on the main CE sample. The evidences show that the bridge between supply chain and circular economy despite emergent shows new trends. Although the supply chain research field is well established and the CE approach is relatively new, it should be noted that the theoretical bridge between both researches bodies need to be enhanced.

Although some advances were performed by exploring opportunities in circular supply chains to nurture the transition towards a circular economy (GENOVESE et al., 2017) and to foster the network reconfiguration (SRAI et al., 2017), further research efforts are needed. The perceptions of the sample showed that some linkage are lacking, mainly among industrial sectors' needs and the collaboration between internal or external partners with the supply chain members to properly implement environmental practices (ZHU, GENG; LAI, 2010a). This is a broader perspective on what remains a gap to be more intensively addressed, rather than tools, best practices to circular economy theory and its supply deployments.

Regarding the supply cluster, the complexity of the CE business context related to the organizational interchange of by-products and waste outputs was slightly mentioned as a background context, the core of the sample focused on the biochemical part of the loop. As already mentioned by Satchatippavarn et al. (2016), it was evidenced that most studies frequently focus on the set of goals needed to achieve a sustainable system, by connecting the whole supply chain, however, the economic factor overlies any other aspect. About possible streams for innovation towards more sustainable supply chains (GARETTI; TAISCH, 2012; POTTING et al., 2016), since it is a move from the *status quo* towards closing the loop (BOCKEN et al., 2016), the evidences presented that: because of the high complexity of circular supply chain operations (BARBER, BEACH; ZOLKIEWSKI, 2012), new business approaches must be stimulated (BOCKEN et al., 2014) in order to accomplish a broader mindset of sustainability imperatives (ABDALLAH et al., 2012).

Another trend that stood out in recent years is the link between circular economy and business model literature, which shows new research opportunities, by discussing value propositions based on offerings (products, services and results) and also on exploring material closed-loop for profit (EVANS et al., 2017). A few papers dealing with the question of dematerialization by the product and service approach were identified, only two bridge the question to the circular economy context, presenting another gap for future research (TUKKER, 2015; VASANTHA, ROY; CORNEY, 2015).

Most of the CE approaches are incremental innovations, indicating minor improvements or small adjustments to existing technologies or processes (ABERNATHY; UTTERBACK, 1978). However, “the move to a circular economy model is an example of a radical change” (BOCKEN; SHORT, 2016, p.312) and to perform a radical change of patterns, major technical breakthroughs may have to be even more emphasized to reach new ways of thinking and doing business.

Another core aspect to the dissemination of a CE strategy through the whole supply chain, transforming it into a circular one, is the necessity of a trained and informed public as well as a systematic regulation and policy system, with better interactions among governmental bodies, policy makers, communities and manufacturing industries. Probably, because CE has evolved from waste generation research, resource use and environmental impacts assessments fields, it has been realized that the economic aspects for manufacturing are intensively being pursued, since they are not yet quite clarified. The advantages for industry must be made more explicit in order to create successful CE implementation, based also on economical supports and pollution regulations from government.

Although the “European Commission adopted a new Circular Economy Package, including revised legislative proposals on waste to stimulate Europe’s transition towards a circular economy; to foster sustainable economic growth and generate new jobs” (Riisgaard, MOSGAARD; ZACHO, 2016), more intensive consequential knowledge dissemination must be performed, probably through education.

Some fundamental challenges to improving the CE transition are related to the fragility of the mechanisms of its economic viability (GENOVESE et al., 2017) by utilizing circular rather than linear supply chains; the main strategy is to re-target production processes following a pattern of enhanced sustainability features (YuAN, BI;MORIGUICHI, 2006). This means that to “achieve sustainable performance, sustainable operations need triple-bottom-line (TBL) thinking that integrates economic, environmental and social issues into its business processes”. That means it should include the reducing of materials in designing, manufacturing, transporting, recycling, reusing and remanufacturing of products. (WU et al. 2017; KLEINDORFER, SINGHAL; WASSENHOVE, 2005).

Therefore, if the boundaries of environmental sustainability are to be pushed, especially in energy and material intensive industries, the understanding of economic and environmental cascade implications, by intensive empirical and practical studies reporting lessons learnt, are fundamental to sustainable supply chain strategies focusing in circular economy principles (NASIR et al., 2017).

6.6 Conclusion

This study contributes to narrow the gap in the literature in three ways. First, it presents a definition of CE based on the semantic-sample, helping to build a consensus around the CE concept. Second, the paper presents a panorama of CE based on a large sample, outlining the yearly evolution, core authors, topics, and journals. Third, based on an in-depth content analysis, the paper presents main trends, content from the main research partnerships between countries and research gaps.

Despite the growing research into the field of CE, it was observed still to be in an exploratory phase, with most of articles adopting exploratory research methods, particularly case studies, and lacking a confirmatory approach and empirical validation. Most of the constructs involved in the CE literature still need to be further refined and a more homogeny nomenclature should be applied.

As implications for practice, we highlight the increasing interest about the topic. From the perspective of a policy maker, the ecoparks literature presents successful examples, exploring how externalities, transaction costs and symbiosis can contribute towards a CE. For companies, new business models are explored, with different kinds of loop approaches, particularly the sharing economy, and this can help organizations have insights on new opportunities to move towards a CE.

This research has limitations related to the use of search engines and the methodological choices concerning the search string, filters and databases selected. The content analysis, despite being performed by a group of four researchers, may generate an interpretation bias. However, the systematic multi-method approach applied (semantic, bibliometric, network analysis and content analysis) helps to mitigate these limitations.

This exploratory work highlights that circularity brings new inspiration and challenges for future research. The study points out the lack of more confirmatory research approaches, applying a TBL perspective, since the focus until now remains from economic-environment perspectives. The CE literature on loop approaches and industrial ecology are not well linked and the theoretical foundations of these two research streams need to be more aligned.

Appendix A. List of Circular Economy definitions in the sample

Reference	Definition
BIRAT (2015)	CE is a contemporary and popular concept that describes how materials and resources should be handled in the future
"CIRCULAR ECONOMY IN AUSTRALIA," (2016)	CE is an alternative model that anticipates and designs for biological and technical 'nutrients' to be continuously re-used at the same quality, dramatically reducing our dependency on sourcing new materials
"COARA - COMMERCIAL ASSET RECYCLING,"(2016)	CE is driven by the desire to use the value in products we already have that might previously have been thought of as waste. But a transition from the traditional linear economy where we use raw materials to make a product, use it and then discard that product once it has ceased to function, or simply becomes out-dated, requires changes in product design, the manufacturing process, supply chain, consumer perception and attitude.
MACARTHUR (2013)	CE is restorative and regenerative by design, and which aims to keep products, components and materials at their highest utility and value at all times, distinguishing between technical and biological cycles
GENG AND DOBERSTEIN (2008)	CE has the potential to overcome current environmental and resource management problems while achieving improvements in resource productivity and eco-efficiency
	CE encourages the creation of a conservation oriented society, seeking to reduce both total consumption and waste production
	CE is normally understood to mean the realization of a closed loop of materials flow in the economic system. Successful implementation of the circular economy concept is one way that China can "leapfrog" past the environmental damages that are typically seen as economies industrialize
GREGSON ET AL. (2015)	CE has emerged recently as a policy goal in the context of rising resource prices and climate change. The aim is to move away from the linear economic model, summarized as 'take– make– dispose' with raw materials in at one end and externalized wastes at the other
	CE appears to decouple economic growth from increasing resource use as well as promoting waste reduction or minimization
	CE will mean choosing specific configurations of materiality and market, with differing moral values, and not just physical or technical mechanisms, to rekindle value in recalcitrant waste materials – in ways that compete with global resource and recycling markets
HAAS ET AL. (2015)	CE is a simple, but convincing, strategy, which aims at reducing both input of virgin materials and output of wastes by closing economic and ecological loops of resource flows
HEPLER (2015)	A successor to the practice of old school "reduce, reuse, recycle" mantras, these examples of unconventional material re-purposing help illustrate the much-hyped circular economy — a more ambitious, and more marketing-friendly, rethinking of how product materials and packaging can be cycled back into supply chains
HOUSE OF COMMONS / ENVIRONMENTAL AUDIT COMMITTEE, (2014)	CE maximises the sustainable use and value of resources, eliminating waste and benefiting both the economy and the environment. It offers an alternative to the predominant current approach where resources are used for one purpose and then discarded
	The idea is not new, and is associated with a range of concepts such as 'cradle to cradle' design and 'industrial ecology', which draw inspiration from biological cycles and emphasise the importance of optimising the use of resources in a system over time. A circular economy includes a range of processes, or 'cycles', in which resources are repeatedly used and their value maintained wherever possible
HU ET AL. (2011)	CE focuses on resource-productivity and eco-efficiency improvement in a comprehensive way, especially on the industrial structure optimization of new technology development and application, equipment renewal and management renovation
	CE focuses on resource-productivity and eco-efficiency improvement in a comprehensive way, especially on the industrial structure optimization of new technology development and application, equipment renewal and management renovation
JIAO AND BOONS (2014B)	CE was defined as a holistic concept covering the activities of 'reduce, reuse, and recycle' in the process of production, circulation, and consumption
LI ET AL.(2010B)	CE aims at closed-loop material and energy systems in all sectors of industry in order to reduce the use of natural resources and the environmental impact
LIEDER AND RASHID (2016A)	CE is to an increasing extent treated as a solution to series of challenges such as waste generation, resource scarcity and sustaining economic benefits
PETERS ET AL. (2007)	The central idea is to close material loops, reduce inputs, and reuse or recycle products and waste to achieve a higher quality of life through increased resource efficiency
SMOL ET AL. (2015)	Transition to a more circular economy requires changes throughout value chains, from product design to new business and market models, from new ways of turning waste into a resource to new modes of consumer behaviour

SU ET AL. (2013)	CE is a sustainable development strategy aiming to improve the efficiency of materials and energy use
	CE is a sustainable development strategy proposed by the central government of China, aiming to improve the efficiency of materials and energy use
	CE can be defined as an economy type with a closed-loop of material flows, which is opposite to the traditional open-ended economy
	CE has been first raised by two Bristh environmental economists Pearce and Turner (1190). In Economics of Natural Resources and the Environment, they pointed out that a traditional open-ended economy was developed with no built-in tendency to recycle, which was reflected by treating the environment as a waste reservoir
TUKKER (2015)	CE is based on the "win-win" philosophy that a prosper economy and healthy environment can be co-existed
"THE WASTE AND RESOURCES ACTION PROGRAMME" (2004)	CE is is an alternative to a traditional linear economy (make, use, dispose) in which we keep resources in use for as long as possible, extract the maximum value from them whilst in use, then recover and regenerate products and materials at the end of each service life
WEI ET AL. (2014)	CE is a model of economic development to maximize the use of resources and protect the environment. Guided by the theory of recycled economy, green supply chain management, as a new notion of management, plays a more and more important role in the development of manufacturing industry in Guangxi
WEN ET AL. (2007)	CE and eco-industry are effective ways to solve sustainable development problems on resources, environment and economy
YUAN ET AL. (2008)	CE was promoted in China as a new development strategy to alleviate the shortage of resource supply by improving the resource productivity and the eco-efficiency of production and consumption
	CE is a political strategy aiming to alleviate the resource scarcity and reduce pollution, and so it is essential to find effective ways to educate or train people so that they can implement the concept into their everyday work and life
	In an ideal CE system, all the materials and energy are effectively utilized and therefore the environmental impacts of development on the ecosystem are reduced to the minimum
ZHANG ET AL. (2009)	CE could be considered a path to sustainable development where industrial symbiosis in eco-industrial parks (EIPs) constitutes an important segment of this strategy
ZHU ET AL.(2010C)	Due to resource scarcity and environmental degradation, a new development concept emphasizing environmental concerns, called the circular economy
ZHU ET AL. (2011A)	CE promotes continuous economic development without generation of significant environmental and resource challenges. It advocates that economic systems can and should operate according to the materials and energy cycling principles that sustain natural systems. CE also emphasizes the recycling of essential materials and energy as well as the capacity for one entity's wastes to be used as a resource by another entity through self-organization capacities
NGUYEN ET AL. (2014)	CE aims to eradicate waste—not just from manufacturing processes, as lean management aspires to do, but systematically, throughout the life cycles and uses of products and their components. Indeed, tight component and product cycles of use and reuse, aided by product design, help define the concept of a circular economy and distinguish it from the linear take–make–dispose economy, which wastes large amounts of embedded materials, energy, and labor.

Appendix B.-Previous CE Reviews

Authors	Year	Title	Journals	Method	Time Range	Articles
LIEDER AND RASHID (2016B)	2016	Towards circular economy implementation: a comprehensive review in context of manufacturing industry	Journal of Cleaner Production	Database search; systematic literature review	1950-2015	215
SUPINO ET AL. (2016)	2016	Sustainability in the EU cement industry: the Italian and German experiences	Journal of Cleaner Production	Database search; review	2000-2013	
PELLIS ET AL. (2016)	2016	The Closure of the Cycle: Enzymatic Synthesis and Functionalization of Bio-Based Polyesters	Trends In Biotechnology	Bio-based polyester review	xx-2016	
LEWANDOWSKI (2016)	2016	Designing the Business Models for Circular Economy-Towards the Conceptual Framework	Sustainability	Database search; literature review	until 2015	94
AMPELLI ET AL. (2015)	2015	CO2 utilization: an enabling element to move to a resource- and energy-efficient chemical and fuel production	Philosophical Transactions of The Royal Society A-Mathematical Physical And Engineering Sciences	Review	2000-2050	
CUCCHIELLA ET AL. (2015B)	2015	Recycling of WEEEs: An economic assessment of present and future e-waste streams	Renewable & Sustainable Energy Reviews	Database search; review	1995-2015	
TUKKER (2015)	2015	Product services for a resource-efficient and circular economy - a review	Journal of Cleaner Production	Database search; literature review	2003-2013	278
DODSON ET AL. (2015)	2015	Bio-derived materials as a green route for precious & critical metal recovery and re-use	Green Chemistry	Review	1998-2013	218
LU ET AL. (2015)	2015	An overview of e-waste management in China	Journal of Material Cycles And Waste Management	Database search; review	2015	
PAN ET AL (2015)	2015	Strategies on implementation of waste-to-energy (WTE) supply chain for circular economy system: a review	Journal of Cleaner Production	successful lessons on WTE supply chains	xx-2015	
WALLS AND PAQUIN (2015)	2015	Organizational Perspectives of Industrial Symbiosis: A Review and Synthesis	Organization & Environment	Database search; systematic literature review	1995-2015	121
VASANTHA ET AL. (2015)	2015	Advances in Designing Product-Service Systems	Journal of The Indian Institute of Science	Database search; literature review	2001-2015	20
MIRABELLA ET AL (2014)	2014	Current options for the valorization of food manufacturing waste: a review	Journal of Cleaner Production		2000-2012	111
XUE ET AL. (2014)	2014	A review on China's pollutant emissions reduction assessment	Ecological Indicators	Database search; literature review	2009-2013	
JIAO AND BOONS (2014A)	2014	Toward a research agenda for policy intervention and facilitation to enhance industrial symbiosis based on a comprehensive literature review	Journal of Cleaner Production	Database search; literature review	2001-2015	37
MANOMAIVIBOOL AND HONG (2014)	2014	Two decades, three WEEE systems: How far did EPR evolve in Korea's resource circulation policy?	Resources Conservation And Recycling	Database search; review	2002-2012	
JONES ET AL. (2013)	2013	Enhanced Landfill Mining in view of multiple resource recovery: a critical review	Journal of Cleaner Production	Database search; literature review	1991-2011	12
SU ET AL. (2013)	2013	A review of the circular economy in China: moving from rhetoric to implementation	Journal of Cleaner Production	Database search; review	2002-2011	-
FENG ET AL. (2012)	2012	Household biogas development in rural China: On policy support and other macro sustainable conditions	Renewable & Sustainable Energy Reviews	Database search; Policy review	2002-2011	
SAKAI ET AL. (2011)	2011	International comparative study of 3R and waste management policy developments	Journal of Material Cycles And Waste Management	review about 3R	xx- 2011	
CHANG ET AL. (2011)	2011	Comprehensive utilizations of biogas in Inner Mongolia, China	Renewable & Sustainable Energy Reviews	Database search; literature review	end 2009	
LI AND YU (2011)	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	Database search; policy review	2003-2008	3
YU ET AL. (2013)	2014	Understanding the Evolution of Industrial Symbiosis Research A Bibliometric and Network Analysis (1997-2012)	Journal of Industrial Ecology	Database search; Bibliometria	1997-2012	164

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7 #P2: PSS creating business for sustainability: the Brazilian Olive Oil case in Mantiqueira Community

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Abstract

This study aims to investigate the influence of Product-Service-Systems on sustainability in small rural communities. The methodological approach is a case-based research. A case of olive processing in the Mantiqueira mountain range community, an inland region from Brazil, is in-depth analyzed. This case is a result-oriented PSS deployment that brings some insights on the creation of new business ecosystems, previously unfeasible due to the large amount of hectares dominated by small proprieties with intensive familiar farming labor. Some aspects of this PSS business model on producing olive oil more intensively introduced in the region by 2012 are the access to more financially viable technologies; financing and partnerships with government; on distance labor training possibility and compact equipment automation for olives processing. It enables new businesses previously limited to producers with large investment possibilities. In addition, it collaborates with the local economy, adding value to products offered by the farmers, promoting sustainable land management through the waste reuse and encourages tourism, job creation and skilled labor training, collaborating with progress in small agricultural towns in the inland.

Keywords: Result-oriented PSS feasibility, Sustainability aspects, Olive Oil Case Study

7.1 Introduction

Product-Service-Systems (PSS) offerings represent nowadays the focus change (Vandermere and Rada) from commercialization of manufacturing products to the new approach of business based on the combination of products and services into an integrated offering (BAINES et al., 2007). Providing result-oriented PSS as a solution for new demands in B2B relationships, even though risky for the provider, since the responsibility for the whole process remains with him (MEIER et al., 2010), is an opportunity to turn income flows more stable to the PSS provider(GAIARDELLI et al., 2014). Besides that, it is the business model more connected to the intrinsic potential of sustainability from types of PSS (YANG et al., 2013). Studies proposed by authors like Lusch et al. (LUSCH et al., 2007) and Raddats and Easinghood (RADDATS;EASINGWOOD, 2010) reinforce the importance of developing more studies in B2B field to identify further characteristics to be developed in this contexts companies.

Another important issue mentioned by Benedettini et al (BENEDETTINI et al., 2015) are the factors that influence the viability of PSS (servitization) in some environments and not in all the contexts. Park et al (PARK et al., 2016) also mentioned the dependency of general needs and business system evolution patterns to create new product-service system concepts. The sustainability assessment in product-service systems is still a remarkable and necessary approach (CHOU et al., 2015), that must take into consideration the triple bottom line (TBL) (ELKINGTON, 1997) based system dynamic and multidimensional approach for the understanding of the product-service system (PSS) influencing sustainability in communities (LEE et al., 2012).

This paper is an ongoing research and aims to answer two research questions: (1) How is PSS introduction capable of influencing sustainability in small farming communities? (2) What are the challenges and benefits of PSS?

To answer these questions this study presents a case-based study performed in the Mantiqueira community of olive farmers. The region has approximately 60 olive producers (mainly small ones), which 90% of the production is intended to the olive oil market. It is expected a production of 50 thousand liters of extra-virgin oil for the year of 2017. The PSS type deployed in the region is the result oriented-PSS, in which a larger olive producer is the owner of the processing equipment and sells his idle capacity to the smaller producers in exchange for a percentage of their production or cash. This new modality of business in the region emerged in 2012 with new knowledge acquisition and techniques of olive growing in partnership with the state government. Since then, the business has brought progress for the region previously coffee producer.

This paper is structured into five sections. The first section has presented the context of the study and research questions. The second one presents the PSS theoretical framework, with the typology, the kind of client focus, as well as PSS sustainability-related aspects. The third section describes the research methodology, followed by the fourth (findings and results, discussions, opportunities, and challenges) and the fifth main conclusions.

7.2 Theoretical Framework

Product-Service Systems are widely known as a system of products, services, networks of actors and support infrastructure that strives continuously to be competitive, meet the needs of customers and have a lower environmental impact than traditional business models (MONT, 2002). They can also be defined as an offering solution, which involves both a product and a service element, to deliver the necessary functionality (WONG, 2004).

In this work, the product-service system (PSS) is considered as a result-oriented business model (VAN OSTAEYEN et al., 2013), which offers a complete solution system for the customer, with inseparable integration of products and services (KUO;WANG, 2012). It aims to facilitate the transition to a system in which products, services, support infrastructure and networks are designed to serve consumers by providing them with quality of life, along with a potential minimization of environmental impacts due to changing consumption patterns (MONT, 2002; CESCHIN, 2013).

In this context, the economic prosperity and sustainable resource management (REIM et al., 2015) can contribute to the transition from a disposal society to a recovery society (COOK, 2014), towards a circular economy (TUKKER, 2015).

7.2.1 B2B Context and Types of PSS

There is also a specific type of PSS for each client. The PSS focused on the Business to Business (B2B) environment, according to Meier et al (MEIER et al., 2010) is the Industrial Product-Service System (IPSS). It is characterized by the planning, development, provision and use of integrated and mutually determined parts of products and services, including its software components in B2B applications, representing a knowledge-intensive socio-technical system. Roy and Cheruvu (ROY;CHERUVU, 2009) present a framework with the main drivers, contextual factors and capacities for an IPSS to be competitive describing that the coordination of the several elements throughout the life cycle to make profit for the solutions provider and value for the clients are: customer accessibility, revenue generation opportunities, global competition, technology development and environmental sustainability.

Besides B2B, PSS business may focus on individual consumers, that is Business to Consumer (B2C). In this modality, the clients of the PSS provider are persons about to change patterns of personal business and consumption, such as the bike sharing systems users (ZHANG et al., 2015).

The types of PSS are commonly classified into three categories (BEUREN et al., 2013): 1) product-oriented, i.e. after-sales, maintenance and Consulting; 2) use-oriented, i.e. bike and car sharing; and 3) result-oriented, i.e. "Pay-per-use" and chemical management services.

The selection of a type of PSS depends mainly on the demands of the customers, the physical products, the attributes of the products, as well as the values associated with the property (TUKKER, 2004; YOON et al., 2012). According to Tukker (TUKKER, 2004), in the product-oriented category of PSS business models, more than selling a product, the provider offers a service related to this product. In use-oriented, a provider makes the product available under rental or lease relationships, but does not sell it; in the result-oriented the provider offers the customer a particular result instead of a specific product or service. The use-oriented and results-oriented PSSs focus on delivering the utility and result to the assets from the manufacturers, encouraging them in the design phase to think about recycling, reuse, remanufacturing and repair – the end of life towards a sustainable design (JUN et al., 2007). Moreover, this PSS type maximizes the utility of physical products, offering greater approximation to sustainability(YANG et al., 2013).

7.2.2 Sustainable Product-Service Systems Perspective

The PSS represents a family of sustainability-focused business model (MAXWELL;VAN DER VORST, 2003; MAXWELL et al., 2006; VASANTHA et al., 2016), designed to meet social needs in an economically and environmentally sustainable manner (HANNON et al., 2015). Therefore, some authors have adopted the term Sustainable Product-Service System, when the PSS actually influences the reorientation of more sustainable trends and consumption practices (MANZINI;VEZZOLI, 2002; MAXWELL;VAN DER VORST, 2003; CESCHIN, 2013; VEZZOLI et al., 2015; VASANTHA et al., 2016).

Lee et al(LEE et al., 2012) present a simplified definition for sustainability in PSS from the perspective of TBL, which not only include monetary profit but also include benefits in terms of social and environmental aspects (ELKINGTON, 1997)

With respect to tactical sustainability activities, most PSS studies consider that their implementation mandatorily generates environmental benefits. However, recent studies have recognized that in some cases they may even have a negative effect on the environment, retaining only economic benefits ((TUKKER, 2004; REIM et al., 2015). The main tactical aspects were associated with the better use of resources and the degree of innovation(REIM et al., 2015). Several authors also suggest the positive impact of the PSS on sustainability particularly on the environmental dimension(MANZINI;VEZZOLI, 2002; MONT, 2002; MAXWELL et al., 2006).

There is a clear theoretical link between the notion of PSS, dematerialization and sustainability, and these concepts present the main influences that make the PSS conceptually sustainable. (MEIER et al., 2010; VASANTHA et al., 2016). With regard to the dematerialization of the products, to make it effective it is necessary to enrich the contents of the services(RADDATS;EASINGWOOD, 2010). Cook (COOK, 2014) stress the need to take into account the environmental, economic and social aspects of PSS, in order to achieve sustainable development. For this study, the sustainability for PSS is defined by Lee et al (LEE et al., 2012). Environmentally sustainable implies that the producing and consuming activities of PSS elements are more capable of resisting resource foundation than the existing product, which has a similar function to PSS. Economically sustainable implies that the PSS is sustainably operational, fulfilling the economic motivation of each stakeholder structurally. Socially sustainable implies that the PSS is sustainably and actively acceptable to socio improving public welfare without invalidating social justice.

The scope and components of the PSS (can be demonstrate by earlier and potential PSS solutions(CHOU et al., 2015). Chou et al (CHOU et al., 2015) states that the nearest approach for PSS requires social cohesion and cooperation between all stakeholders. Meaning that, satisfaction is not restricted to consumer use, but expandes to community participation or knowledge/information sharing.

7.3 Research Methods

This study is an in-depth exploratory case study and uses a qualitative approach to reach some insights about this research environment. As prescribed by the literature, this case-based approach is used for understanding the investigated phenomena, and collecting empirical evidence. The investigation focus is on the viability of result oriented PSS business for sustainability and the unit of analysis are the business of small and large producers of Olive Oil in Serra da Mantiqueira.

Data collection and Analysis

Data was collected through semi-structured interviews with people directly involved with the PSS business. The interviewed people were: Large producers owners of Olive Oil processing machines (3); Small producers without processing equipment (4), Agricultural Research Center from the state of Minas Gerais (EPAMIG) (1), Olive Producers Association from the state of Minas Gerais (1).

To assist in the elaboration of the research protocol for this case study and to define key criteria

for its execution and analysis, the propositions of Lee et al (LEE et al., 2012) and Chou et al (CHOU et al., 2015)guided the main topics covered by the interviews, Table1.
In addition to the interviews, secondary data provided by the company, such as documents, reports, folders and company website were used. Several sources of information were considered for the triangulation of the collected data aiming to reduce some bias in the case analysis (VOSS et al., 2002).
Concerning the economic analysis, usually results in companies, mainly small business owners, are measured in financial return(STERMOLE;STERMOLE, 1987). This can be translated into a cash flow brought to present value. In this work, a 21-year horizon was considered, with a minimum rate of attractiveness of 9%. The criterion of success is the positive NPV. An analysis of NPV (what cash flow would represent today) on investment has also been made, it represents how many times the NPV equals the investment, which must be greater than 1 (STERMOLE;STERMOLE, 1987).

Table 1 – Topics covered by interview script

Constructs	Topics covered	Authors
Result oriented PSS business	pay-per-use strategy, community building, resource sharing,	(TUKKER, 2004; MORELLI, 2006; YOON et al., 2012; YANG et al., 2013)
Product -Service Integration	Product durability, ease of use, size, new technology, customization, Added value (e.g., repair), feedback (e.g., discount), burden reduction, Education, synergy,welfare	(GAIARDELLI et al., 2014; CHOU et al., 2015; REIM et al., 2015; VASANTHA et al., 2016)
Sustainability value	Life cycle extension, job creation, waste reduction, Skill empowerment, community transformation, human care, etc.	(MEIER et al., 2010; LEE et al., 2012; CHOU et al., 2015; PARK et al., 2016)
Factors of satisfaction	Cost saving, time saving, feeling of convenience, Knowledge acquiring, participation, sense of commitment etc.	(MONT, 2002; GAIARDELLI et al., 2014; BENEDETTINI et al., 2015; ZHANG et al., 2015)

7.4 Results and Discussion

The first Brazilian Olive Oil was processed in Maria da Fé town in 2008, state of Minas Gerais at EPAMIG (state agro industrial technological center). Currently there are about 60 producers in the Mantiqueira region on 1800 hectares (composed of mountain ranges on the frontier between São Paulo and Minas Gerais). Today there are 15 processing equipment in the region with different capacities. Many of them perform the processing of other producers besides the owners olive production. It favors large producers using idle capacity and small producers adding product value, since without processing, it would be sold much cheaper. This Technological Center and the Olive Farmers Association manager state that 90% of olive from this region are focused on olive oil production and in 2017 the estimated production is 45 tons of olives and 50 thousand liters of olive oil.

This PSS business can be framed as olive farmers who have processing machines oversized for their own production; selling the olive oil extraction service during the idle period. Small farmers that use this service must pay for it whether in cash (U$10/l) or in production percentage (30%).

An important issue is that the processing equipment must be located near the planting place, since the olives should be processed on the same day, preferably soon after harvesting, to avoid oxidation and loss of olive oil quality. In this PSS system, the farmers schedule the olive processing with the PSS provider before the harvest, and soon after it they deliver the fresh olives themselves in the PSS provider facilities. They can contract only the extraction, or the potting as well.

The processes and equipment are presented in Figure 1, the simplest system has two phases and the most complete one three. The smaller ones usually have only two phases. The overall efficiency of olive harvest kg is about 10% to 12% in liters of olive oil production.

The first equipment came from Italy (2008), however nowadays similar are already produced in the country. All the processing equipment in the region are considered compact. Small machines process 100kg/h and cost approximately U$ 63.000; medium ones (300kg/h) U$125.000 and large ones (500kg/h) U$188.000.

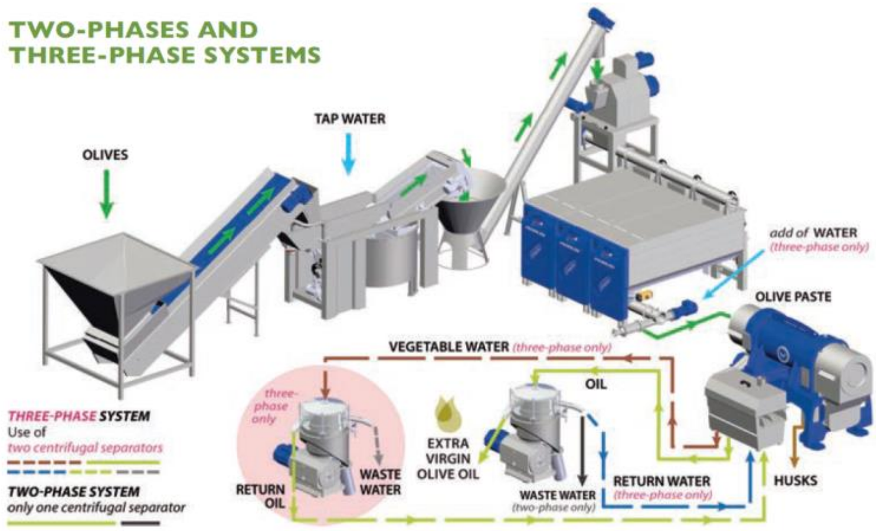

Figure 1 - Olive Processing Equipment. Source: Pieralisi Brochure (2017)

The smaller equipment does not have the centrifuge for the final separation of water and oil, so the processing must be realized at the highest rotation and water cannot be added to make better use of the fruit. It requires an extra step afterwards for filtration and decantation. Larger machines that have a vertical centrifuge, depending on the olive, may have a smaller rotation during the process because there is addition of water, do not require filtration, and the decantation period for the container is reduced, only for the release of aromatic properties and taste of oil. Note that automation was strictly necessary to enable this PSS implementation, as well as skilled job creation.

The possible types of result oriented PSS in this business environment are in Table 2.

Table 2 - Possible types of result oriented PSS

Investor Type	PSS offering Characteristics
(A) “result-oriented” PSS	Only machine, without olive grove. Sell services only Accepts only cash payment Advantage: Lower investment and operation cost Disadvantage: Higher business risk due to low revenue diversification
(B) “result-oriented” PSS + Farming	Machine and olive grove. Sells olive oil and idle equipment capacity Accepts cash or part of olive oil production as payment Advantage: Higher profitability and lower business risk Disadvantage: Higher investment and operation cost

About the selling revenue, although farm gates and inland sales predominate, more structured producers are managing to reach gastronomic emporiums and capitals restaurants, entering the "gourmet" olive oil business.

7.4.1 Environmental Aspect

The environmental aspect of the sustainability is intrinsic to this PSS business model, since lifecycle extension is an important environmental aspect related to the machinery maintenance given its high investment cost and high dependence. Since there are no spare machines, the disponibility and confiability must be of 100%.

In addition, this model enables proper effluents treatment, because if there is a single processing machine, then the owner is responsible for the treatment of all effluents. The effluents in this case are the pie (husks), which are the solids, and water after it is separated from the olive oil. These two effluents are used in the field as fertilizers, characterizing a case of circular economy. The husks for being rich in oil, can also be used as fuel, due to its high burning feature.

7.4.2 Social Aspect

Instead of having one large producer dominating a region with mechanized harvesting, there are several small producers that perform organic cultivation and manual harvesting. Most of the cultivation in Serra da Mantiqueira is realized in a declivity, which makes it also difficult to mechanize harvesting. Another aspect is that without machines there is greater possibility of avoiding injuries in the fruits which contribute to the beginning of the fruit oxidation, reducing the oil quality, so the acidity increases.

Related to the knowledge acquiring, participation and sense of commitment, the machine operators should be skilled because each type of equipment and each type of olive requires different treatment by the operator.

During processing, two skilled operators are required to manage the olives processing. Since the adjustment of the equipment depends on the characteristics of each production, the taste of the operators besides their technical skills needs to be sharpened. The olives, although being of the same class in a batch, for example Arbequinas (Spanish origin), may have been harvested earlier or later than recommended, it influences the type of treatment during the processing (rotation for pressing, rotation for centrifugation, type of cleaning, filtration and decantation time) and mainly in the olive oil per kilogram income expectation of processed fruit. The bottling and labeling is done manually at the PSS provider facility after the decanting period.

Another important aspect in the inland is that this business creation stimulates and encourages tourism based on products and services commercialization from the region. Producers and their employees promote walking events on the plantations, freshly pressed olive oil tasting, presenting the developed infrastructure and promoting restaurants and small towns in the countryside, often in partnership with the town hall itself.

7.4.3 Economic Aspect

From the interviews it was identified that the operational costs (permanent and temporary employees, fertilization, pest control, management, consultants / experts, etc.) is about 10% of the production value. When the PSS is contracted by the farmer, there is still a 30% rate that must be paid to the service provider.

The average idle capacity of the machine is of the order of 25%, according to interviews, the additional financial return obtained by the owner of the equipment is therefore of that order.

In the current scenario, there is a large producer that owns a machine (PSS provider) beyond its own production and several small producers that contract the services of this PSS provider to manage the process of olive oil extraction.

Table 3 - Simplified Economic Analysis of the 6 possible scenarios in this environment

Simplified Investment Analysis	Total Investment(TI)	Oper. Costs	Net Present Value (PV)	Payback	PV /TI	Status
	10³U$	%	10³U$			
Large Producer + Equipment	531,250	10%	495,245	10years , 5 months and 20 days	0,93	Feasible
Large Producer+ Equipment+"result-oriented' PSS	531,250	10%	751,869	9 years , 1 months and 24 days	1,42	Feasible
Large Producer + No Equipment	343,750	40%	122,839	13years , 10 months and 16 days	0,36	Feasible
Small Producers + Equipment	83,125	10%	-21,535	-	-0,26	Unfeasible
Small Producers + Equipment + "result-oriented" PSS	83,125	10%	-6,1371	-	-13,54	Unfeasible
Small Producers + No Equipment	20,625	40%	7,370	13years , 10 months and 16 days	2,80	Feasible

Taking this information into account as well as the price for the land (U$22thousand/he), value of the olive seedlings (U$3,00/un), minimum spacing between trees (15m²/tree) and others factors already mentioned, as initial investment, besides 6 years of intensive cultivation before the first harvest. Other investment issues were considered as follows: olive productivity per tree (7,5kg); efficiency of 10% in oil extraction; bottling units of 250ml and 100% sales production by the medium cost of U$12.00/bottle, taxes of 35% and extra net income of 25% in the case of being a PSS provider. The equipment processing purchase occurred in a single installment, in the “zero” period of the cash flow. The resume of this simplified economic analysis of 6 possible scenarios in this environment was performed to compare which one would be more feasible (Table 3).

7.4.4 Discussion

In the large agribusiness model, dairy industry for instance, one large producer can have a much larger machine, own production and buy someone else's production selling 100% with his label. In a cooperative, small producers join to form a group where each one offers a quota of money and they buy facilities needed to industrialize their production. However, in this hybrid model, there are larger players, which have the machine, who may also plant olives. The great advantage is buying much larger machines, to process their own production, and a few more. So the machine ends up being cheaper, because of the scaling up, in other words the lower specific cost.

This business environment may be compared to the business of an Uber user for the small produces. Since the major investment related to the cost of the car in Brazil (U$20.000) has already occurred, the cost of an Uber race (about U$20 depending on the itinerary) is used for improving the financial margin by the car owners, which in this case are the large producers. So why would small producers immobilize a large amount of money, investing in equipment, maintenance, depreciation, fuel, insurance, if they use so little of it? The amount of benefits is not worthy. For the small producer, the return is a fact, evidenced by the numbers in Table 3.

In other words, the advantage for large companies are that they can, with the same capital investment, process their own and others production, and put everything on its label. The total investment will be amortized with the production of other small owners, with about 30% of the small ones production.

Comparing to previous business in region for the small producers: first, farmers do not need to join a cooperative and immobilize large amounts of money. Second, they do not have any administrative cost from the cooperative, office, accounts, representing legally less bureaucratic work. Third, they are not responsible for maintenance and learning how to deal with the equipment, they focus on their main product process which is olive and olive oil, outsourcing the main cost of the production. In summary, reduces the risks for the small producer and amortizes the equipment value for the larger ones (Figure 2).

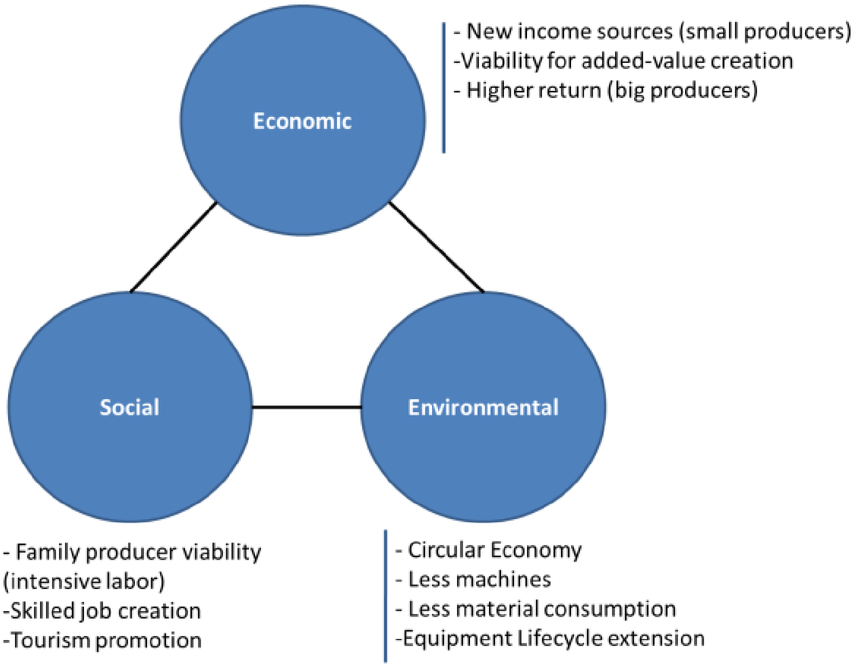

Figure 6: Advantages and Limitations for Small and Large Producers

7.4.5 Challenges and Opportunities

Although the most modern equipment has already arrived in the field, the extraction is still handmade and depends very much on the machine operators knowledge. There is great dependence on the individual skills of operators in the process flow as well as in bottling and labeling. There is still space for more technological systems within the financial producers possibility as an opportunity to develop new automated processes that are more accessible to this environment. The main positive aspects are, therefore related to creating and adding value to the activities performed by the farm workers that require training and specialization. There is also the price barrier, since the national product, because of the low volume of production, costs expensive even in comparison with imported high profile. Most people and restaurants in Brazil know little and see no advantage in paying for a higher value-added product. Sustainability (TBL) aspects see Figure 3.

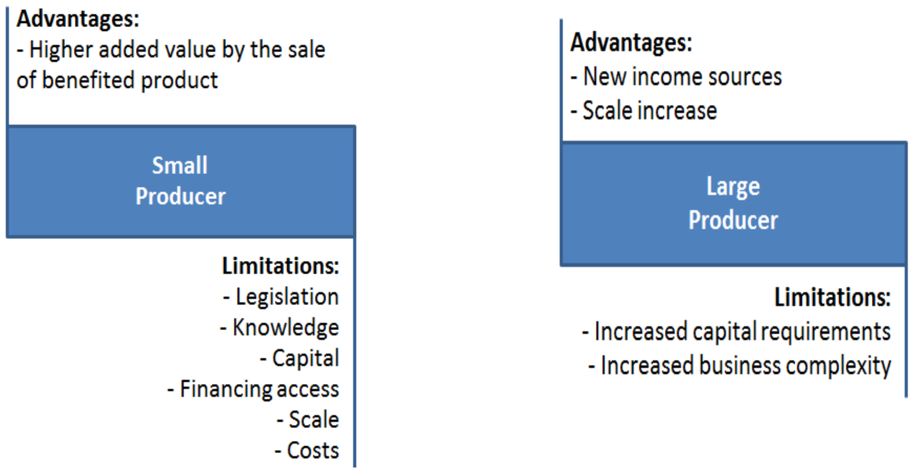

Figure 7 - Main aspects of sustainability (TBL) for this PSS result-oriented case

7.5 Conclusion

This study shed light on two research questions, which were: (1) How is PSS introduction capable of influencing sustainability in small farming communities? (2) What are the challenges and benefits of PSS in this environment? This research insights suggest that PSS enables the sustainable production of olive oil in the region. In face of empirically observed evidences, for the small producers of Serra da Mantiqueira the use of PSS, is the only option to make their business feasible. For the large producers to offer the PSS is a way to increase revenues, use the idle capacity of their equipment and reduce the payback period. Besides, it makes the business of the small producer economically feasible and improves the profitability of the larger ones building synergies that help to face the main challenges of the small producers.

In the current scenario, whose configuration is a large producer with a machine providing PSS, the business developed in this region innovated. It meets the three pillars of sustainability. In the economic aspect, the PSS developed guarantees the profitability by maximizing revenue of all involved. In the social aspect, it enables the family agriculture of small producers due to the intensification of the labor use; favors the diffusion and acquisition of technical knowledge through the practice and study of new cultivation solutions in the region, reducing the rural exodus by the greater aggregation of value in the commercialized products, besides promoting tourism. In the environmental aspect, it allows the organic management in the olive groves and promotes circular economy, because the processing waste is used as fertilizer in the own plantations. Another important fact is the reduction of the consumption of resources because there is a single processing machine attending to several farms, minimizing the amount of used material and the number of needed equipment to serve the region. As well as equipment lifecycle extension, considering the close maintenance attention, since the equipment are core to many producers, they are not allowed to failures during each harvest (February, March and April).

Further research could explore the influence in sustainability results by the adoption of cooperatives. Would it improve the results here presented?

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8 #P3: Connecting Healthcare Product Service Systems (PSS) and the circular economy idea - a “hop on-hop off” experience from literature

Journal:	Journal of Cleaner Production
Authors:	Aline Sacchi Homrich; Marly Monteiro de Carvalho
Status:	Re-submitted to the Journal of Cleaner Production according to reviewers’ comments

Abstract

This paper presents a perspective of the academic literature in product/service systems (PSS) and the circular economy within the healthcare sector discussing some aspects regarding digital technologies. The aim is to identify the main themes discussed to build up propositions about the status of the research developed so far in the Healthcare PSS sector. The methodology combines bibliometric, network and content analysis on the literature published by means of Scopus and Web of Science databases. The proposed conceptual framework, exploring the life cycle of a healthcare PSS approach under the circularity perspective, makes this approach unique. Moreover, it explores the moderating effect of digital technologies and lifecycle management. Research will contribute to broaden the understanding of the challenges regarding sustainability issues and propose future research pathways.

Keywords: Product/Service Systems; Healthcare; Circular Economy; Digital Technologies; Lifecycle.

Highlights

- Product/Service Systems (PSS) are explored in the healthcare sector under the circular economy perspective.
- A systematic literature review (SLR) and content analysis (CA) are used to identify the status of the main researched themes in the field.
- Current trends and future research opportunities are suggested.

8.1 Introduction

The global healthcare sector is growing rapidly due to emerging markets and ageing populations (DELOITTE, 2016). Furthermore, the global healthcare revenue expected for 2019 is around 1.855 billion dollars (FROST; SULLIVAN, 2018). It is no novelty that the healthcare sector involves a high amount of assets, a great volume of budget and many employed people around the world (MCDERMOTT, 2018). Moreover, the equipment suppliers tend to be limited in numbers and be highly experts in the field due to the inherent characteristic of business relationships, such as being highly regulated, and in most cases, having severe penalties for non-accomplishment of accorded goals (HOLMES et al., 2018). Only a very few new incomers face the adventure of being part of product and/or service providers in the risky healthcare business. At the extreme, any delay or misunderstanding in processes and especially results may cause severe damage, such as the loss of a human life, indicating that there is no space for errors in the health sector (STOETT et al., 2018).

In this sense, integrated solutions such as PSS may contribute to this goal, especially regarding health infrastructure and interconnected medical equipment and devices. The aim is for the delivery of integrated performance instead of singular products to be connected. Although the majority of PSS in healthcare applications regard the creation of value for/with customers in forms of managed services or operating services, it still remains an under-explored field.(XING; RAPACCINI; VISINTIN, 2017).

Being a product service system is a joint offer that "tangible products and intangible services" may provide (TUKKER; TISCHNER, 2006). It must be emphasized that although product service systems (PSS) are often suggested as being a more sustainable business solution (KJAER et al., 2018), because of the potential improvement of performance efficiency (CE) (STAHEL, 2010), "the interactions of various elements functions in PSS depend on the agreement between heterogeneous elements in a relatively loose structure" (LEE AND PARK, 2015).

The shift towards product-service systems provides a basis for companies to move to circular business models (WITJES; LOZANO, 2016). However, despite the wide academic discussion around the subject, sustainability and specific aspects regarding the circular economy (CE) umbrella (BLOMSMA; BRENNAN, 2017; HOMRICH *et al.*, 2018) in the healthcare sector, it still needs to be discussed. Firstly, because of the problems of material waste within the sector, and secondly because of the potential difficulty of introducing circular strategies to it (Kane *et al.*, 2018). On the other hand, it is true that the introduction of disposable products has reduced infection in the sector and greatly improved health outcomes. Those are just a few aspects of a macro perspective of a sector that should provide health, one fundamental right for humanity, the 17th sustainable development goal (SDG) (UNITED NATIONS, 2015).

The efficiency move is not something new. There were many moves to look at waste with recycling possibilities. Yet at this point, mankind has realized that proper waste prevention is only possible with good design and monitoring of industrial activities (BARTL, 2014) over the life cycle of any product or service. In this sense, the objective of this paper is to fill the gap between areas such as PSS and CE in healthcare, by bridging the developed literature in those research fields to date. The aim is to present an overview of the main topics discussed identifying drivers, challenges and opportunities through the main aspects taken into consideration until recently.

Therefore, the research questions guiding this paper are:

RQ 1: Which are the main topics relating the PSS business model to the healthcare context?

RQ 2: Which are the main topics relating the circular economy to the PSS business model in the healthcare context?

To answer these research questions, a mixed method approach is adopted, combining bibliometric/network and content analysis in different samples of articles. The combination set of keywords used were: Healthcare, Product Service Systems and Circular Economy. The search was performed in the literature published in the main journals from Web of Science and Scopus databases in the fields of strategy, innovation, sustainability and entrepreneurship up to December 2018.

The paper is organized into four sections. After this introduction, the second section is a theoretical background on PSS, challenges in healthcare and the circular economy. The third section refers to research methods and explains the methodological procedures of the systematic literature review in detail. In the following section, the main findings are presented, through networks and discussions on evolution, linking PSS and CE literature. In the final section are the main conclusions of this paper, trends and additional topics to further explore the research field.

8.2 Theoretical Background

8.2.1 Product Service Systems in Healthcare

A PSS can be defined as a special form of 'servitization' emphasizing utilization or performance instead of product ownership (BAINES *et al.*, 2007;ADEOGUN *et al.*, 2010); in other words, it is a process of creating value by adding services to products (PAWAR; BELTAGUI; RIEDEL, 2009), improving total value for the customer including benefits to the environment, since producers are more responsible for its products/services through practices of take-back, recycling and refurbishment, reducing waste through the product's life (Baluch *et al.,* 2017). In fact, literature suggests that by migrating from traditional product-focused business models to usage-focused ones, the potential for the circular economy increases.

The extent of academic literature in healthcare PSS can be analyzed in distinctive perspectives from an operational, tactical and strategic level of analysis. In healthcare PSS related to the operational level and the design phase at the beginning of life (BoL) of a PSS, several issues stood out, whether regarding new propositions of PSS (YIP *et al.,* 2014; DAGBALI *et al.,* 2015; MITTERMEYER *et al.,* 2011), or new modular products for a PSS development (SHIKATA *et al.,* 2013), or even innovations around the home (Liedtke *et al.,* 2012). The complexity of the operational level also extends to the development of proper tools for the most distinct purposes, such as modelling of the information flow in a PSS (DURUGBO *et al.,* 2012) and interconnected systems to monitor health within a POC (point of care) device (ANDEOGUN *et al.,* 2010). Service complexity (KREYE *et al.,* 2015) and modularity (FLORES-VAQUERO *et al.,*2014) are frequent subjects within this context since the whole idea of stakeholders' relationship depends on this level of organization. Moreover, the concern about the functional performance of a PSS is also suggested as core issues by Lee et al. (2015) and Mittermeyer *et al.,* (2011).

On a tactical level, the multiple stakeholder network is largely mentioned as an enabler of PSS due to the close relationship needed between providers and customers within the business ecosystem. The customer's role and participation in decisions are not only suggested as fundamental but also the customer's level of satisfaction is one of the main outcome-variables in a PSS, gathered with functional performance.

According to Moore, (2013), a business ecosystem can be defined as an interconnected network among various ecosystem members, such as customers, suppliers, partners and other stakeholders (financial service firms, trade associations, standard bodies, labour unions and government). It is an economic community conducting business activities in which collaborative and innovative efforts of all members make them accomplish greater goals than they can do on their own (MOORE 2013). Added to this perspective, government and regulation play a fundamental role, clearly influencing the market and its players in the health care sector (MITTERMEYER *et al.,* 2011).

Regarding the strategic level, the generation or added value is emphasized as "the effort of increasing the perceived benefits of a product or service when compared with the sacrifices associated with its purchase" (TILLMANN *et al.*, 2010). According to these authors, the focus of value generation is, however, not only on the final users but especially on other groups of stakeholders (e.g. society). Broadening the perspective, the whole structure seeks to develop a better competitive strategy, which according to Neely (2009), happens by moving up the value chain, innovating and creating sophisticated products/services, consequently, preventing firms from having to compete on the basis of cost. It makes the shift in the whole business ecosystem (BE). The capital available for investments influences the business ecosystem configuration and pathway in terms of provider-pushed or customer-pulled, and each pathway led to a more complex resource-dependent network in the BE or led to low dependence among actors in the BE, respectively (PEREIRA; KREYE; CARVALHO, 2019).

8.2.2 Circular Economy and Sustainability

The circular economy (CE) is characterized as an economy that is restorative and regenerative by design in which products, materials and resources are maintained in the economy for as long as possible, and the generation of waste is minimized (MORLET *et al.*, 2016). CE distinguishes between technical and biological cycles and in many cases, the implementation of CE in companies requires changes in their business models, which can be reached through Product Service Systems (PSS), for instance (PAGOROPOULOS *et al.*, 2017). In this sense, according to Mont *et al.* (2006), for a proper contribution to environmental improvement, three aspects must be fulfilled: the product's manufacturer has interest in increasing their longevity through maintenance and upgrading. Moreover, at the end of the products' life, they return to the producer for remanufacturing and recycling and waste management hierarchy (reduce, reuse, and recycle) should be respected.

Still aligned with CE and PSS, intensive use of goods can occur not only through leasing and renting, but also through sharing and pooling arrangements. CE principles, if well designed, may bring economic and environmental benefits to the company (EMF, 2013). Furthermore, to reach sustainability, the social dimension of CE should also be pursued (MURRAY *et al.*, 2017). Thus, the company must adjust its value proposition to embrace also social aims (BRESSANELLI *et al.*, 2018).

Although widely discussed, sustainability in the circular economy context reminds us that the triple bottom line aspects (TBL) (ELKINGTON, 1997) need to be taken into consideration. In fact, for any endeavour to be considered sustainable, positive balanced effects in economic, social and environmental aspects must be accomplished. However, in most of the CE literature, contributions in the economic and environmental dimensions of sustainability are recurrent themes (GHISELLINI; CIALANI; ULGIATI, 2016). Besides them, the circular economy has enormous potential for realizing sustainable value creation in social dimensions (STAHEL, 2013).

From an environmental perspective, when products reach their end of life (EOL), they are supposed to be reused, remanufactured or recycled in order to extend product and material life (KALVERKAMP *et al.*, 2017). The circular economy technical cycles are interconnected into four layers in a cascade relationship until the final users: the first connecting directly the users "share"; the second connecting from the service providers on"maintain/prolong"; the third connecting from the product manufacturers on "reuse/redistribute"; the fourth connecting from parts manufacturers on "refurbish/remanufacture" and "recycle" (ELLEN MACARTHUR FOUNDATION, 2013).

Furthermore, according to the Ellen MacArthur Foundation (2015) companies adopting CE should convert their value proposition by means of three CE principles. The first principle is the necessity to increase the utilization of assets and products, thus pursuing resource efficiency: "Preserve and enhance natural capital". The second principle is the extension of the lifespan of products:" Optimize resource yields". The third principle is to close the loop, enhancing multiple product lifecycles of reuse, remanufacturing, and recycling: "System effectiveness" (KALVERKAMP *et al.*, 2017).

8.2.3 The role of Digital Technologies and Life Cycle

In the healthcare sector, different organizational networks rely on technology to communicate and share health information about patients. Virtual arrangements comprising diverse people, who are geographically dispersed, use information and communication technologies to conduct their business (DUL *et al.*, 2012). Therefore, in an information economy where information is increasingly exchanged, such as currently, data collection technology has emerged with the fast improvement of IoT (Internet of Things) and telecommunication technologies (LIM *et al.*, 2018). Digital technologies are then, critical enablers of the transition to CE at each life cycle stage (LEWANDOWSKI, 2016; BRESSANELLI *et al.*, 2018). Intelligent assets and connectivity are fundamental to operationalize the circular economy (MORLET *et al.*, 2016), specially by optimizing forward material flows and enabling reverse material flows (PAGOROPOULOS *et al.*, 2017).

The maturity of digital technologies within the life cycle stages are, nevertheless, still questionable (PAGOROPOULOS *et al.*, 2017). However, regarding PSS, digital technologies that have recently being introduced, such as IoT and Big Data, have a high potential to help in developing an environmentally more benign PSS (KJAER et al., 2016). Their main functionalities are suggested by Bressanelli *et al.*, (2018) to be: improvement of product design, attraction of target customers, monitoring and tracking of product activity, offering of technical support, providence of preventive and predictive maintenance, optimization of the product usage, upgrade of the product, enhance of renovation and end-of-life activities.

Still according to Bressanelli *et al.,* (2018), IoT through sensors collecting data from the usage phase can help to improve product design and better fulfill customer's needs (BAINES; LIGHTFOOT, 2014). Knowing how customers are using the installed products can also assist companies to improve marketing activities and target new customers (RUST; HUANG, 2014). On the other hand, product condition, status, location (BAINES ; LIGHTFOOT, 2014; SPRING ; ARAUJO, 2017) and usage can be available to each single customer to enable product sharing, for example. IoT may also help companies to provide better technical support, repair, spare parts management and provide preventive and predictive maintenance through Big Data analysis (BAINES; LIGHTFOOT, 2014; RYMASZEWSKA *et al.,* 2017). Furthermore, personal advice may be offered to optimize usage phase, reduce energy consumption, and upgrade digital elements (RYMASZEWSKA *et al.,* 2017), in the case of smart products. Regarding end-of-life, companies can access real-time product location and condition (FRANCO, 2017), for a better execution of collection, refurbishment, remanufacturing and recycling activities (LEWANDOWSKI, 2016; BRESSANELLI *et al.,* 2018).

However, the mentioned technological functionalities are most related to the middle of life (MOL-product's distribution, use and maintenance) (BRESSANELLI *et al.,* 2018). Organizations investing in digital technologies with the focus on closing the loop need to make efforts at the beginning of life (BOL-design and production) such as design-for-remanufacturing; design-for-recycling (GO *et al.,* 2015; BAKKER *et al.*, 2014), or specifically at the end of life (EOL –reuse, remanufacturing, recycling, disposal) through reverse logistics (KUMAR; PUTNAM, 2008).

8.2.4 Conceptual framework

Based on the literature review on product service systems (PSS) in healthcare (HC) and its intersection with sustainability and the circular economy, the schematic conceptual overview that drives this research is presented in Figure 1.

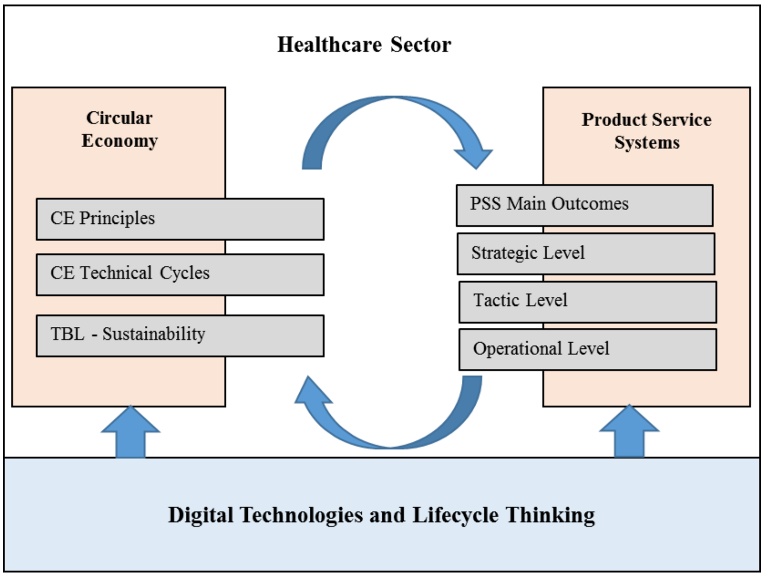

Figure 1: Schematic conceptual overview

As shown in Figure 1, the aim was to investigate the relation between PSS and CE, looking to understand the role of digital technologies and lifecycle in the context of the healthcare sector.

8.3 Methodological Approach

To identify how the literature on healthcare PSS has been developed, a literature review approach was selected to explore the available body of knowledge. A mixed-method approach was applied: a systematic literature review (SLR) mixing a quantitative bibliometric and network analysis, and qualitative content analysis with the support of some software-tools through each phase (see Figure 2).

Bibliometric studies are gaining relevance, due to the high number of scientific publications (IKPAAHHINDII, 1985) and also the ability to use techniques to quantify and identify research cluster relevance in the field through search engines in scientific databases. The combination of content analysis with bibliometric analysis aims for an in-depth understanding of the main research constructs and their relationship (DURIAU; REGER; PFARRER, 2007) to identify trends, frequently discussed topics and gaps that may exist within the field (CARVALHO; FLEURY; LOPES, 2013).

8.3.1 Sampling procedures

The first research phase is the bibliometric approach, by surveying the existing literature in two scientific databases, Web of Science (WoS) and Scopus. Two different string-sets were used (see Appendix A and Table 1), grouping a total sample of indexed papers in December 2018. Keyword network analysis was performed in a second phase to provide an overview of relationships between constructs and identify main themes. The third phase is the content analysis in which the core relationships for PSS in HC and CE are presented through a coding network. From this background, the fourth phase regards the synthesis process, in which main propositions and concluding remarks are positioned.

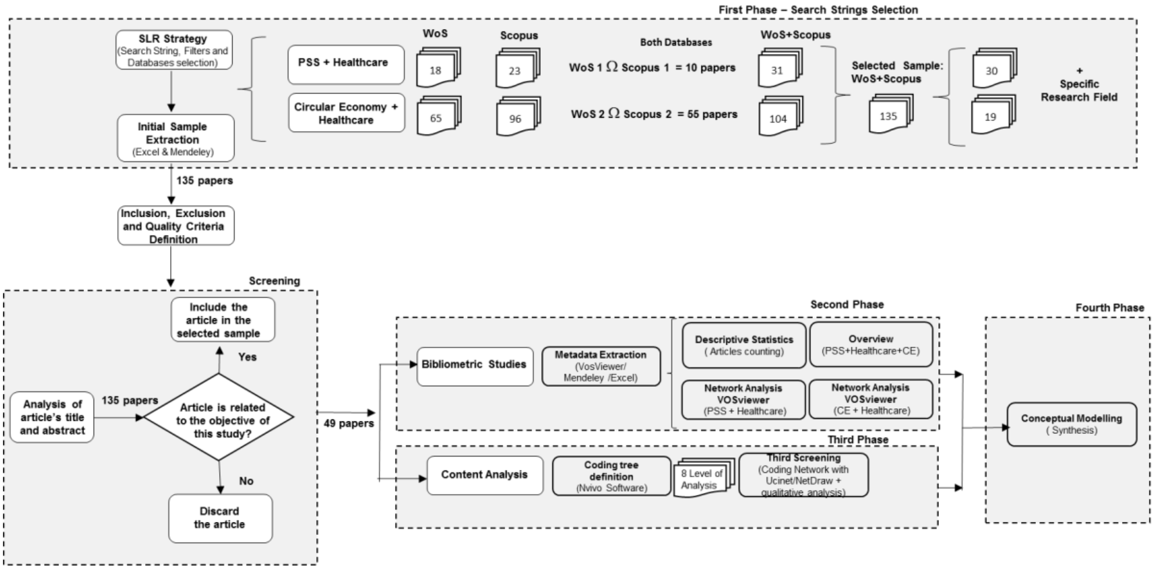

Figure 2 –Systematic Literature Review Workflow

To obtain the samples, articles published in indexed journals (having their impact factor calculated by the JCR -Journal Citation Report) were selected from both databases (WoS and Scopus). These platforms were chosen because they include articles from other databases, such as ProQuest and Wiley. It provides, therefore, fundamental metadata for the bibliometric analysis, including summaries, references, number of citations, list of authors and keywords. All the articles recorded in these databases until December 2018 were considered in the initial set.

After several simulations, the searched strings used to perform this research were defined, as shown in Appendix A. Product service systems (PSS) in healthcare (HC) have been addressed in industry by various companies, but the publications about the intersection between these fields and the circular economy (CE) are still scarce, or nonexistent if the two researched databases (WoS and Scopus) were taken into consideration. Thus, we opt to maintain two samples as described in Table 1, which shows the number of publications per database and final sample amount.

Table 1: Description of the researched sample

Strings Composition	# Papers - Wos	# Papers - Scopus	# Papers WoS+Scopus	Selection
PSS + Healthcare	18	23	31	30
CE + Healthcare	65	96	104	19
Total Sample			135	49

Note: variations of the words also included, see Appendix A for further search strings details

8.3.2 Data analysis

To answer the research questions, bibliometric, network analysis and content analysis were applied to two samples of articles as shown in Table 1. This was mandatory due to the non-existence of papers discussing the three subject themes together.

The software used to illustrate the keywords network was VOSviewer version 1.6.9 (VAN ECK; WALTMAN, 2010). The evolution of the published papers of both samples over the years is also explored, as the means of a descriptive statistics comparison. Mendeley, EndNote X9, Access and Excel were used to operate data. To perform the content analysis, according to the recommendations of Duriau *et al.,* (2007) and Mayring (2014), the following main steps were applied: review idea (research questions, search strategy and coding), operationalization (frequency counts and cross-tabulations), and report results and main conclusions (interpretation).

The main content analysis codes are shown in Table 4. As suggested by Carvalho *et al.*, (2013), the starting point codes definition were insights from bibliometric keywords networks, combined with a deductive approach based on the theoretical background, and further in the content analysis new codes emerge. To support the content analysis and the coding process, the NVivo 12 Plus software (BAZELEY; JACKSON, 2013) was applied. To perform further analysis on the salience and relationship among the codes, the descriptive model of core/periphery structure analysis (BORGATTI; EVERETT, 2000), and the codes network illustration with the softwares UCINET 6.512 and NetDraw (BORGATTI; EVERETT; FREEMAN, 2002) were respectively applied.

8.3.3 Content analysis procedures

The final codes selection to perform the content analysis, further propositions and an overview of the researched samples are shown in Table 4.

Table 4: Main Codes and respective abbreviations to content analysis.

Main Subject	Related Theme	References	Identified Codes	Abbreviations
Digital Technology and Lifecycle	Lifecycle	WANG et al. (2011); KALVERKAMP et al. (2017)	Beginning of Life	BOL
			Middle of Life	MOL
			End of Life	EOL
	Digital Technologies	BRESSANELLI et al. (2018); LIM et al (2018); PAGOROPOULOS et al. (2017)	IoT – Internet of Things	IoT
			ICT*- Communication Technologies	ICT
			POC – Point of Care	POC
			Information Flow/ Exchange	IFE
Circular Economy	TBL	ELKINGTON (1997); GHISELLINI et al.(2016)	Economic	ECO
			Social	SOC
			Environment	ENV
	CE Technical Cycles	ELLEN MACARTHUR FOUNDATION, (2013); MORLET et al., (2016).	Maintain – prolong	CE1
			Reuse – redistribute	CE2
			Refurbish – remanufacturing	CE3
			Recycle	CE4
			Share	CE5
	CE Principles	ELLEN MACARTHUR FOUNDATION, (2013).; MURRAY et al., (2017); KALVERKAMP et al. (2017)	Preserve and enhance natural capital	CEP1
			Optimize resource yields	CEP2
			System effectiveness	CEP3
PSS Business Model	PSS Main Outcomes	KREYE et al.(2015); LIU et al (2019); SHIKATA et al.(2013)	PSS Functional performance	PSSP1
			Customer Level Satisfaction	PSSP2
	Operational Level	KREYE et al.(2015); YIP et al.(2015); DURUGBO et al.(2012)	Tool	OL1
			Design	OL2
			Service Complexity / Modularity	OL3
	Tactic Level	YIP; JUHOLA (2015); DURUGBO AND RIEDEL (2013), YIP et al.(2014)	Customer's Role / Participation	TL1
			Stakeholders Engagement /Network / PSS Enablers	TL2
	Strategic Level	NEELY (2009); PEREIRA et al., (2019); MOORE, (2013); MITTERMEYER et al (2011); BALUCH et al. (2017).	Competitive Strategy	SL1
			Value Concept	SL2
			Business Ecosystem	SL3
			Business Model	SL4
			Government/Regulation	SL5

8.4 Results

In this section, the data analysis is explored for the two samples described in Table 1. Then, a merger analysis of the two samples towards the coding schema is also presented.

8.4.1 Publication evolution Over the Years

In Figures 3 and 4, the overview of publications from both samples (PSS and CE respectively) over the years. No filters were applied considering the time span, journals, research areas. etc. The only filter applied was type of documents (articles and reviews).

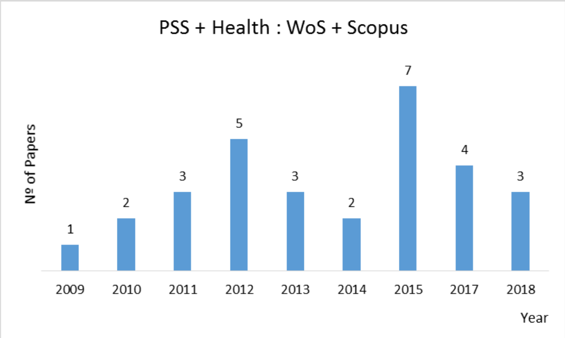

Figure 3:Number of Published Papers about Product Service Systems and Health Over the Years (sample extracted from Web of Science and Scopus)

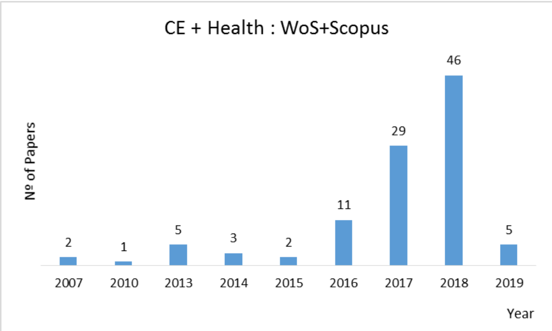

Figure 4: Number of Published Papers about Circular Economy and Health Over the Years (sample extracted from Web of Science and Scopus)

Remarkably, the amount of research published on circular economy and health is growing steadily (Figure 4), reaching a climax in 2018 with 46 papers. On the other hand, the amount of research published on PSS and health is scarce and relatively stable, reaching a climax in 2015 with 7 papers (Figure 3). It is interesting to note that the papers belong to each sample exclusively and no overlap was observed.

8.4.2 Keywords Networks Analysis

In Figure 5 and Table 2, the five main clusters for the sample *PSS and Healthcare research* were identified: PSS Business Model (red), Design (green), Modeling/Simulation (blue), Stakeholders' Network (purple), and Health care (yellow). This analysis was performed with metadata from Web of Science (WoS) and Scopus databases in the software Vosviewer.

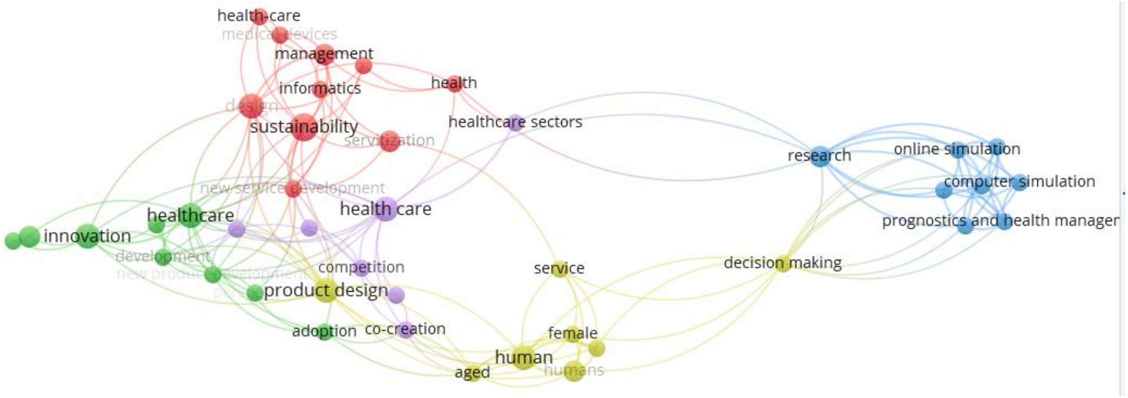

Figure 5: : PSS and Healthcare Network Visualization with the software Vosviewer

Source: WoS and Scopus files (31 papers) minimum of 2 occurrences a term

Since the number of papers belonging to the sample *PSS and Health* is smaller, the research clusters appear weakly connected (Figure 5), represented by the thin thickness of the lines. The clusters, main cluster's components, explanatory comments and main references of each cluster are summarized in Table 2. Two clusters stand out, PSS Business Model (red) and Modelling/Simulation (blue). The first, more generic, discusses strategic aspects regarding information flow. The second regards the functional performance of equipment through modelling and simulation operations. The illustration represents clearly the intrinsic opposite nature of the two approaches.

Table 2: Five main groups of research in Product Service Systems and Health and their themes.

Main Clusters	Components	Comments	References
PSS Business Model (red)	Design Ergonomics Health / Health-care Sectors Informatics Management Servitization Sustainability Medical Devices	This group's main subject is the need of information flow (informatics) design to deal with the product-service system business model, through the management of medical connected devices or contractual aspects to accomplish sustainable servitization	KREYE ET AL. (2015);YIP ET AL (2014); WANG ET AL (2011); GRUBIC ET AL (2011);MITTERMEYER ET AL (2011); ADEOGUN ET AL (2010); TILLMANN ET AL (2010); TONELLI ET AL (2009)
Design (green)	Innovation New Product Development New Service Development Sustainable Design Development Adoption Healthcare Perspective Stakeholder	The main themes researched in this group are the development and adoption of new products/ services with the engagement of different stakeholders taking sustainability also in consideration.	BOEREMA ET AL. (2017); YIP ET AL. (2015); SHIKATA ET AL. (2013); LIEDTKE ET AL. (2012); DUL ET AL. (2012);

Modelling/Simulation (blue)	Computer Simulation Dynamic Behaviours Online Simulation Prognostics and Health Management Systems Engineering Research	The main researched subject in this group is the use of simulation and modelling to integrate ,usually machines in a determined system, and monitor their long term efficiency and performance	LIU ET AL.(2019); MALEKI ET AL.(2018); ;LEE ET AL.(2015); TEIXEIRA ET AL.(2013); TEIXEIRA ET AL.(2012); DURUGBO ET AL.(2012)
Stakeholders' Network (purple)	Co-creation Competition Complex Networks Holistic Approach Healthcare Sustainable Development	The subject discussed refers to the network of stakeholders and their need to co-create competitive systems with broader overview in healthcare to reach sustainable development	YIP AND JUHOLA (2015); JOO AND MARAKHIMOV (2018); ZHANG ET AL.(2015); DURUGBO AND RIEDEL (2013); MITTERMEYER ET AL.(2011); TONELLI ET AL.(2009)
Health care (yellow)	Decision Making Product Design Service Humans Male Female Aged	This group is composed of researches regarding different aspects to human decision making for products and services	LIM ET AL.(2018); NURHADI ET AL.(2017); BALUCH ET AL.(2017); ZHAO ET AL.(2015); DAGBAGLI ET AL.(2015); ANDREONI ET AL.(2012)

Note: Not every groups'component can be seen in the network due to scale proportions allowed by the software Vosviewer.

Similar analysis was performed for the sample *CE and Healthcare research.* In Figure 6, the four main clusters identified are: Environmental Monitoring/ Materials (red), Economic Impact (green), Life cycle (blue), and Environmental Management (yellow). In Table 3, the four clusters are depicted in terms of components and key references.

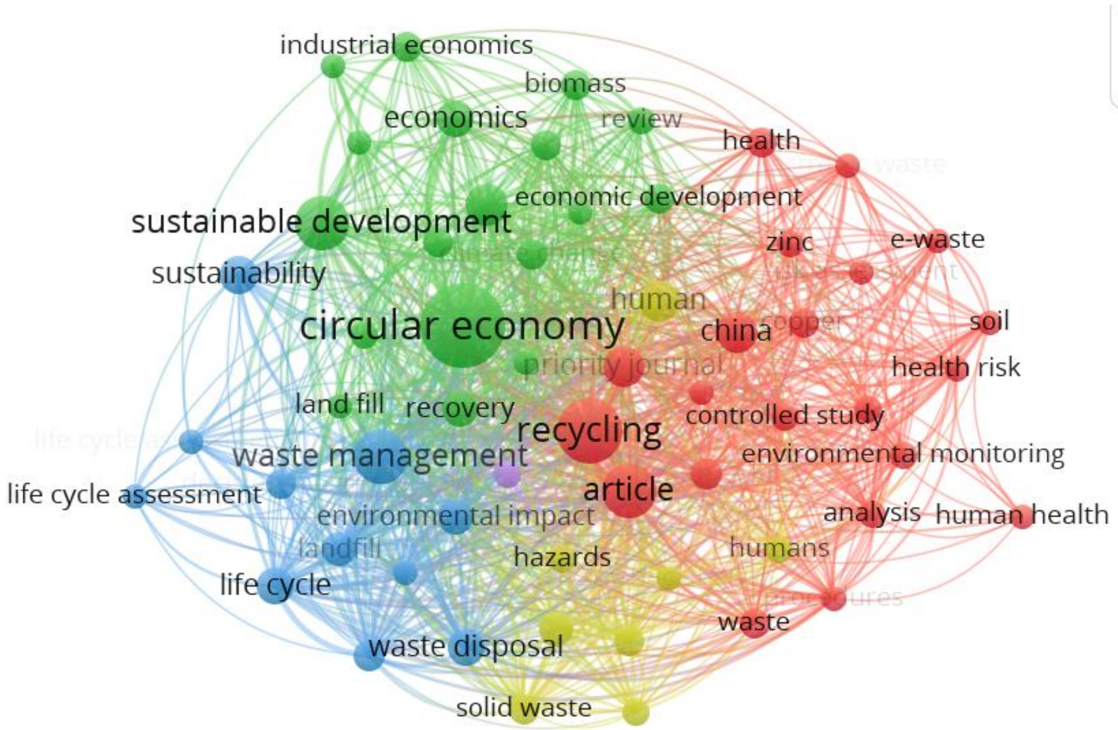

Figure 6 : PSS and Circular Economy Network Visualization with the software Vosviewer

Source: WoS and Scopus files (104 papers) with minimum 5 occurrences of a term

The number of papers belonging to this sample *CE and Health* is almost 4 times larger than the previous one, which is the reason they are so densely connected (Figure 6), represented by the aggregation and thickness of the lines. The clusters, main cluster's components, explanatory comments and main references of each cluster are summarized in Table 3. Two clusters stand out, the Environmental Monitoring/ Materials (red), which regards most of materials circularity and waste targeting studies (reuse, recycle, refurbish). The second is Economic Impact (green), which analyses the different kinds of economic effects and aspects of circular economy aspects.

Table 3: Four main groups of research in Circular Economy and Health and their themes.

Main Clusters	Components	Comments	References
Environmental Monitoring/ Materials (red)	China Controlled study Copper E Waste / Electronic Waste Environmental Monitoring Health / Health Risks Human health Pollution Recycling Risk Assessment Soil Waste Zinc	The most frequent related keywords in this research group refer to kinds of waste (e-waste) and pollution or identified materials that may be recycled or reused such as copper and zinc, aligning controlled studies with risk management, health risks and human health with environmental monitoring.	LU ET AL. (2015); SCHROEDER ET AL., (2018); LAHL AND ZESCHMAR-LAHL, (2013); CONG ET AL. (2017); ALI AND GENG (2018)

Economic Impact (green)	Biomass Circular Economy Climate Change Economic and Social Effects Economic Aspect/Development Energy Environmental Protection European Union Industrial Economics/Symbiosis Land fill Municipal Solid Waste Recovery Sustainable Development Water Pollution	This group focus on economic effects, aspects and development of circular economy. Eventual impacts related to biomass, water pollution, land fill, municipal solid waste, energy and climate change integrate this group, in which European Union plays an important role in recovering and fostering environmental protection and sustainable development	KOOP AND VAN LEEUWEN (2017); PICATOSTE ET AL., (2018); ZHU AND CHERTOW (2016); WINANS ET AL., (2017)
Life cycle (blue)	Decision Making Environmental Impact/Economics Life Cycle Assessment/Analysis Sustainability Waste Disposal/ Management	To proper decision making over waste disposal and management, environmental impact and economics must be properly analyzed within the life cycle perspective to aim at more sustainable procedures.	STAHEL (2007); WIESER AND TRÖGER (2016); VIANI ET AL. (2016); RIECKHOF AND GUENTHER, (2018); KANE ET AL. (2018)
Environmental Management (yellow)	Economic Analysis Environmental Management Hazardous Waste Industrial Waste Solid Waste Waste Treatment	To cope with solid, industrial, hazardous waste, it is mandatory, not only waste treatment, but efficient environmental management, which include economic analysis to better perform.	NIERO ET AL. (2017); HENS ET AL. (2018); ALARANTA AND TURUNEN (2017); STAHEL (2013)

Note: Not every groups'component can be seen in the network due to scale proportions allowed by the software Vosviewer.

8.4.3 Content Analysis

An in-depth qualitative content analysis of the papers was performed with the help of NVivo. Then, a cross-tabulation of the coding schema was performed with Excel and further on UCINET software. This procedure was performed for both samples separately and then the overall sample merged.

8.4.3.1 Literature on PSS and Health

From the *PSS and Health* sample analysis, the core/periphery analysis in figure 7, identifies eight codes as core class BOL, MOL, IFE, ECO, SOC, OL3, ICT, OL2 with a fit correlation of 0.8611. This analysis was performed with the software UCINET.

The matrix mainly displays the correlation between the codes and shows the most correlated ones as core class codes, as identified in the upper left square. The main codes basically represent that the most recurrent subjects discussed in the PSS and Health sample refer to the beginning and middle of lifecycle, the economic and social aspects of TBL, issues on information flow and communication technologies, design and service complexity aspects. The interrelation among the codes are the basis of the network illustration in Figure 8. The thicker the lines, the more frequent and connected the subjects are in the sample.

Core/Periphery fit (correlation) = 0,8611

Core/Periphery Class Memberships:

Core: BOL MOL ECO SOC ICT* IFE OL2 OL3
Periphery: EOL ENV IoT POC OL1 TL1 TL2 PSSP1 PSSP2 SL1 SL2 SL3 SL4 SL5 CE1 CE2 CE3 CE4 CE5 CEP1 CEP2 CEP3

		1 BO	2 MO	10 IF	4 EC	5 SO	13 OL	8 IC	12 OL	7 Io	3 EO	11 OL	9 PO	6 EN	14 TL	15 TL	16 PS	17 PS	18 SL	19 SL	20 SL	21 SL	22 SL	23 CE	24 CE	25 CE	26 CE	27 CE	28 CE	29 CE	30 CE
1	BOL	18	7	7	15	12	9	6	16	2	4	1	2	9	4		5	7	6	4	3	5	1		2	1	2	2	6	4	3
2	MOL	7	18	10	14	7	7	6	9	3	4	2	2	5	4	3	9	3	4	2	3	3	2	1	3	1	4	1	4	6	7
10	IFE	7	10	14	12	4	7	9	10	4	1	2	3	2	2	2	6	3	3	1	1	3	1		4	1	5	1	4	4	4
4	ECO	15	14	12	24	10	12	9	16	3	4	2	2	8	5	2	9	6	8	3	2	6	2	1	3		4	2	7	7	6
5	SOC	12	7	4	10	15	5	3	11	1	3	1	1	7	4	1	3	4	5	5	3	3			1	1	1	2	5	4	2
13	OL3	9	7	7	12	5	14	5	11	2	1	1	2	2	3	3	4	4	3	2	1	4	2	1	2		3	1	4	7	3
8	ICT*	6	6	9	9	3	5	11	9	4		1	3	2	2	1	3	3	3	1	2		1		4	1	4		4	2	3
12	OL2	16	9	10	16	11	11	9	20	4	2	2	3	7	4	1	4	6	6	4	3	4	2		4	1	4	2	8	5	2
7	IoT	2	3	4	3	1	2	4	4	4			2				1		2		1				3	1	3		3	1	1
3	EOL	4	4	1	4	3	1		2		4			4	1		1	2	1			1							1	1	2
11	OL1	1	2	2	2	1	1	1	2			3					1		1			1						1	1	1	1
9	POC	2	2	3	2	1	2	3	3	2			3		1	1	1		1		1		1		1	1	1		1		1
6	ENV	9	5	2	8	7	2	2	7		4			9	2		2	3	3	2	1	3						1	2	2	2
14	TL1	4	4	2	5	4	3	2	4		1		1	2	7	2	1	1	1	2	1	1	1		1		1		3	2	1
15	TL2		3	2	2	1	3	1	1				1		2	3	1			1		1	1				1			2	1
16	PSSP1	5	9	6	9	3	4	3	4	1	1	1	1	2	1	1	10	1	4	1	2	4	1	1	1	1	2	1	1	3	6
17	PSSP2	7	3	3	6	4	4	3	6		2			3	1		1	7	1	2	2		1		1		1		1	1	
18	SL1	6	4	3	8	5	3	3	6	2	1	1	1	3	1		4	1	9	1	2	4			2	1	2	1	3	1	2
19	SL2	4	2	1	3	5	2	1	4					2	2	1	1	2	1	5	1	1						1	1	2	
20	SL3	3	3	1	2	3	1	2	3	1			1	1	1		2	2	2	1	4		1		1	1	1		1		1
21	SL4	5	3	3	6	3	4		4		1	1		3	1	1	4		4	1		6					1	2	1	3	2
22	SL5	1	2	1	2		2	1	2				1		1	1	1	1			1		2								
23	CE1		1		1		1										1							1						1	1
24	CE2	2	3	4	3	1	2	4	4	3			1		1		1	1	2		1				4	1	4		4	2	1
25	CE3	1	1	1		1		1	1	1			1				1		1		1				1	1	1		1		1
26	CE4	2	4	5	4	1	3	4	4	3			1		1	1	2	1	2		1	1			4	1	5		4	3	2
27	CE5	2	1	1	2	2	1		2			1		1			1		1	1		2						2	1	2	
28	CEP1	6	4	4	7	5	4	4	8	3	1	1	1	2	3		1	1	3	1	1	1			4	1	4	1	8	4	2
29	CEP2	4	6	4	7	4	7	2	5	1	1	1		2	2	2	3	1	1	2		3		1	2		3	2	4	8	3
30	CEP3	3	7	4	6	2	3	3	2	1	2	1	1	2	1	1	6		2		1	2		1	1	1	2		2	3	7

Figure 7: Core/Periphery Analysis: Product Service Systems and Health sample.

Figure 8 illustrates that the discussion in the literature is focused on the intense relationship with the economic (ECO) aspect of the triple Bottom Line demonstrating the core business concern in the sample, economic sustainability. The social (SOC) aspect is evidenced due to the inherent character of the sample, which is the healthcare sector repercussion. Moreover, the operational level of analysis (OL), particularly design (OL2) and service complexity/ modularity (OL3), is part of the core themes in the PSS of which the strongest links are TBL and BOL and MOL. Remarkably, it is a challenge to identify some environmental (ECO) concerns, especially connected to the end of life (EOL) of the discussed themes in the sample.

Figure 8 explores visually the main relationship among codes in *Product Service Systems and Health* sample.

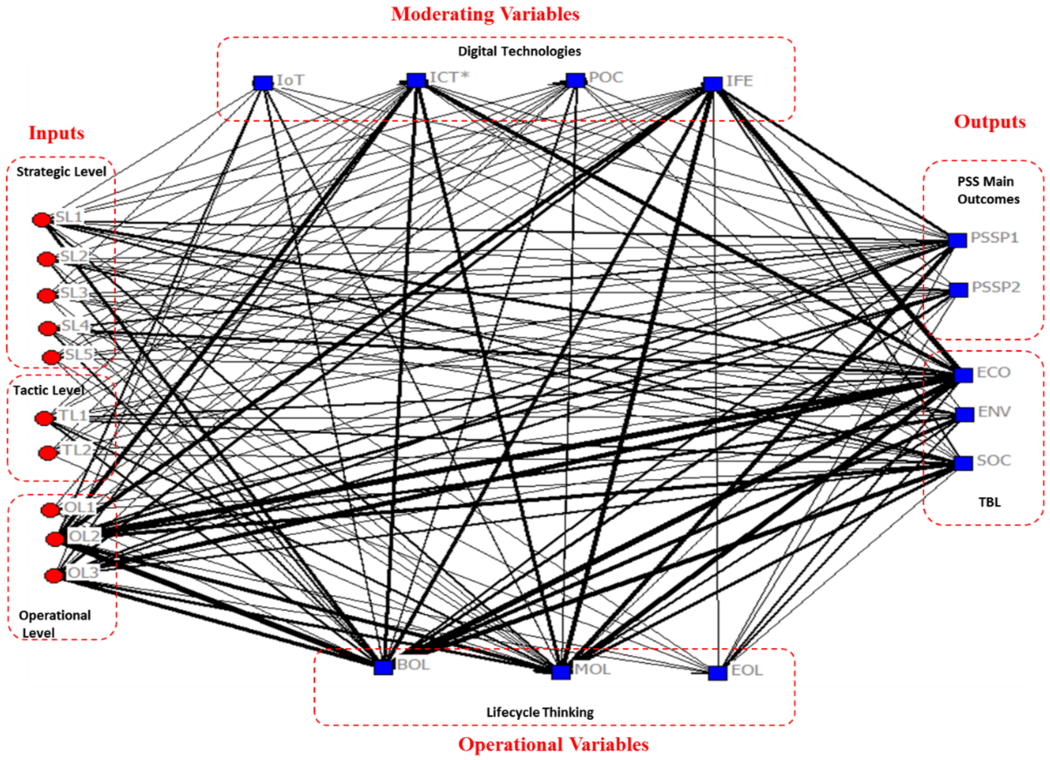

Figure 8: First Sample Network: Product Service Systems and Health

Regarding digital technologies, the thickest lines are connecting information and communication technologies (ICT) and information flow/exchange (IFE), underlining how prominent these aspects are in the sample. Most of the literature deals with the strong need for good design, good information exchange through ICT, among stakeholders, to reach good functionality/performance, focused on the economic aspect of the business. Special attention should be given to the thick connection between IFE- OL2-MOL-ECO but also between ICT-OL2-BOL-MOL-ECO, emphasizing the moderating aspect of digital technologies perspectives. They act as enablers between the inputs (PSS in healthcare) and outcomes (PSS performance evaluation and TBL).

8.4.3.2 <u>Literature on CE and Health</u>

From the core/periphery analysis of *CE and Health* sample shown in figure 9, nine codes are identified as core class CE1, CE2, EOL, ECO, CEP3, ENV, CEP2, CE4, CEP1 with a fit correlation of 0,9375. This analysis was performed with the software UCINET.

Although the economic (ECO) perspective from TBL sustainability is a core aspect, it is evident that the highest concern regards the end of life (EOL) and environmental issues (ENV). The main aspects of the circular economy technical cycles are maintain/prolong (CE1); reuse/redistribute (CE2) and recycle (CE4), complementing the approach, the three CE principles, preserve (CEP1), optimize (CEP2) and system effectiveness (CEP3) which are equally discussed. Different from the previous sample, in which the functional performance was the most related aspect, in this sample, customer satisfaction is emphasized.

Core/Periphery fit (correlation) = 0,9375

Core/Periphery Class Memberships:

Core: EOL ECO ENV CE1 CE2 CE4 CEP1 CEP2 CEP3
Periphery: BOL MOL SOC IoT ICT* POC IFE OL1 OL2 OL3 TL1 TL2 PSSP1 PSSP2 SL1 SL2 SL3 SL4 SL5 CE3 CE5

		23 CE	24 CE	3 EO	4 EC	30 CE	6 EN	29 CE	26 CE	28 CE	2 MO	5 SO	12 OL	10 IF	7 Io	1 BO	16 PS	17 PS	18 SL	19 SL	20 SL	21 SL	22 SL	8 IC	9 PO	25 CE	11 OL	27 CE	13 OL	14 TL	15 TL
23	CE1	8	8	7	8	7	8	6	7	7	2	5	1			3		2	1			1	4			6	1	3		1	1
24	CE2	8	11	10	10	9	11	6	10	10	2	5	1			3		4	1			1	5			7	1	3		1	1
3	EOL	7	10	14	12	10	14	7	13	13	2	5	1			3		4	1			2	4			6	1	2		1	1
4	ECO	8	10	12	16	12	15	9	12	14	2	8	1			3		6	1			2	6			7	2	3		1	2
30	CEP3	7	9	10	12	13	13	9	10	12	2	4	1			3		4	1			2	4			7	2	3		1	1
6	ENV	8	11	14	15	13	18	10	14	17	2	7	1			3		5	1			2	5			7	2	3		1	1
29	CEP2	6	6	7	9	9	10	10	8	10	2	5	1			3		2	1			2	3			5	2	3			
26	CE4	7	10	13	12	10	14	8	14	14	2	6	1			3		4	1			2	5			6	1	3			
28	CEP1	7	10	13	14	12	17	10	14	17	2	7	1			3		5	1			2	5			6	2	3			
2	MOL	2	2	2	2	2	2	2	2	2	2	2				2		2	1			1	1			2		2			
5	SOC	5	5	5	8	4	7	5	6	7	2	8				2		4	1			1	5			4		3			1
12	OL2	1	1	1	1	1	1	1	1	1			1			1										1					
10	IFE																														
7	IoT																														
1	BOL	3	3	3	3	3	3	3	3	3	2	2	1			3		2	1			1	1			3		2			
16	PSSP1																														
17	PSSP2	2	4	4	6	4	5	2	4	5	2	4				2		6	1			1	3			3		2			1
18	SL1	1	1	1	1	1	1	1	1	1	1	1				1		1	1			1				1		1			
19	SL2																														
20	SL3																														
21	SL4	1	1	2	2	2	2	2	2	2	1	1				1		1	1			2				1		1			
22	SL5	4	5	4	6	4	5	3	5	5	1	5				1		3					6			3		2			1
8	ICT*																														
9	POC																														
25	CE3	6	7	6	7	7	7	5	6	6	2	4	1			3		3	1			1	3			7		3		1	1
11	OL1	1	1	1	2	2	2	2	1	2																	2				
27	CE5	3	3	2	3	3	3	3	3	3	2	3				2		2	1			1	2			3		3			
13	OL3																														
14	TL1	1	1	1	1	1	1																			1				1	1
15	TL2	1	1	1	2	1	1					1						1					1			1				1	2

Figure 9: Core/Periphery Analysis: Circular Economy and Health sample

In Figure 10, it explores the main relations among codes in the *CE and Health* sample. Remarkably, the main insight from this analysis is the evidence of how far the circular economy discussion is from digital technologies (ICT, IFE, IoT) to enable the “fast” operationalization of environmentally friendly actions, since they are isolated and non-related variables. The absence of a digital technologies' relationship and further materials traceability, manifest how CE is still at a conceptual level, even though there is some discussion about circular actions implementation on specific materials (reuse, recycle, refurbish). The great challenge is tough, to structure the deployment of CE philosophy into performance as well as operational, tactic and strategic levels actions inside a business model context. Note that comparing this sample to the PSS and health sample, they are practically two mutually exclusive groups, since their core themes are completely diverse from one another.

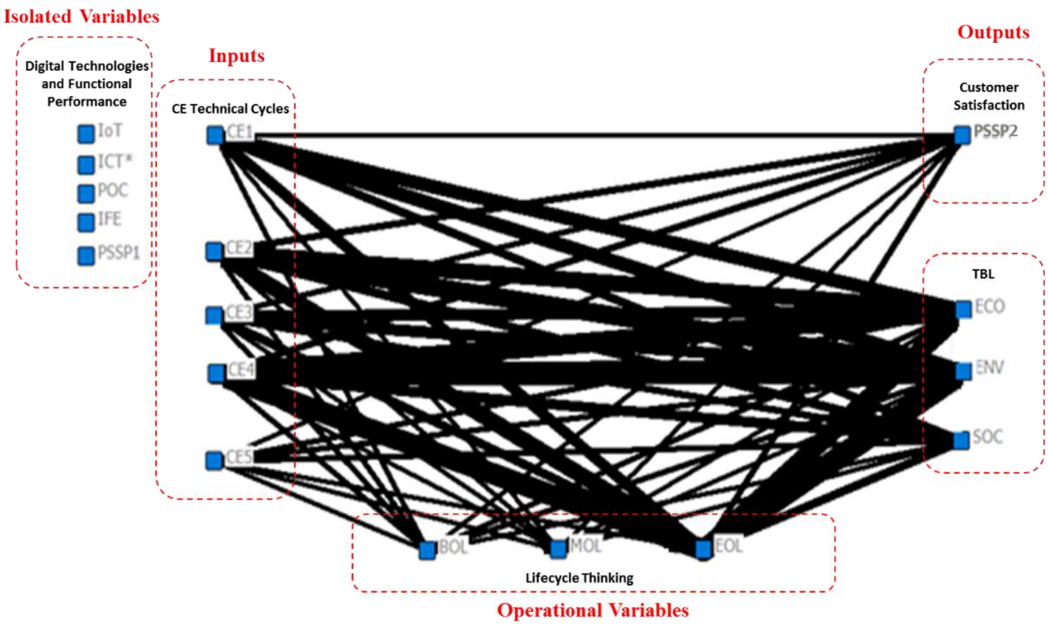

Figure 10: Second Sample Network: Circular Economy and Health

Figure 10 shows that CE Technical Cycles, Lifecycle Thinking and Sustainability dimensions are equally aligned in the second sample, which reflects on the construct satisfaction. Regarding the density and thickness of the line, the end of life is a prominent subject in the sample, differently from the previous one. Regarding the other constructs in this sample, they are uniformly and densely discussed.

8.4.3.3 Literature on PSS, CE and Health

Finally, the content analysis of the merged sample with all the article results are in Figure 11 and 12.

From the whole sample, the core/periphery analysis is shown in Figure 11, identifying twelve codes as core class: BOL, MOL, EOL, ECO, SOC, ENV, CEP2, CEP3, CE2, CEP1, CE4, OL2, with a fit correlation of 0.838. This analysis was performed with the software UCINET.

Note that merging the two samples, any of the digital technology codes are included, therefore, not considered as belonging to the core subject group. On the other hand, lifecycle thinking (BOL, MOL, EOL), sustainability dimensions (ECO, SOC, ENV) and circular economy principles (CEP1, CEP2, CEP3) belong integrally to the core class. Specifically, from the *PSS and Health* sample, only the operational level variable design (OL2) emerged and from the *CE and Health* sample only reuse (CE2) and recycle (CE4) emerged in the core class group.

It can be inferred that life cycle thinking and sustainability dimensions are conceptually known and mentioned at some level in most of the literature as well as the three circular economy principles: preserve and enhance natural capital, optimize resource yields and system effectiveness. However, the deployment of those concepts into strategic, tactic and operational levels is scarce. The only operational dimension more intensively discussed is the design (OL2). On the other hand, from the five technical cycles, only reuse/redistribute and recycle are more discussed, which is a counter intuitive aspect of the whole sample, regarding the other three cycles refurbish/remanufacturing; maintain/prolong and share. It is useful to mention that it was expected that maintain/prolong would play a role, since maintenance is well known and used in any product and service subject area.

Number of random starts: 5
Maximum iterations: 100
Density of core->periphery ties: NA
Density of periphery->core ties: NA

Core/Periphery fit (correlation) = 0,838

Core/Periphery Class Memberships:

Core: BOL MOL EOL ECO SOC ENV OL2 CE2 CE4 CEP1 CEP2 CEP3
Periphery: IoT ICT* POC IFE OL1 OL3 TL1 TL2 PSSP1 PSSP2 SL1 SL2 SL3 SL4 SL5 CE1 CE3 CE5

		1 BO	2 MO	3 EO	4 EC	5 SO	6 EN	29 CE	30 CE	24 CE	28 CE	26 CE	12 OL	10 IF	7 Io	8 IC	16 PS	17 PS	18 SL	19 SL	20 SL	21 SL	22 SL	23 CE	9 PO	25 CE	11 OL	27 CE	13 OL	14 TL	15 TL
1	BOL	21	9	7	18	14	12	7	6	5	9	5	17	7	2	6	5	9	7	4	3	6	2	3	2	4	1	4	9	4	
2	MOL	9	20	6	16	9	7	8	9	5	6	6	9	10	3	6	9	5	5	2	3	4	3	3	2	3	2	3	7	4	3
3	EOL	7	6	18	16	8	18	8	12	10	14	13	3	1			1	6	2			3	4	7		6	1	2	1	2	1
4	ECO	18	16	16	40	18	23	16	18	13	21	16	17	12	3	9	9	12	9	3	2	8	8	9	2	7	4	5	12	6	4
5	SOC	14	9	8	18	23	14	9	6	6	12	7	11	4	1	3	3	8	6	5	3	4	5	5	1	5	1	5	5	4	2
6	ENV	12	7	18	23	14	27	12	15	11	19	14	8	2		2	2	8	4	2	1	5	5	8		7	2	4	2	3	1
29	CEP2	7	8	8	16	9	12	18	12	8	14	11	6	4	1	2	3	3	2	2		5	3	7		5	3	5	7	2	2
30	CEP3	6	9	12	18	6	15	12	20	10	14	12	3	4	1	3	6	4	3		1	4	4	8	1	8	3	3	3	2	2
24	CE2	5	5	10	13	6	11	8	10	15	14	14	5	4	3	4	1	5	3		1	1	5	8	1	8	1	3	2	2	1
28	CEP1	9	6	14	21	12	19	14	14	14	25	18	9	4	3	4	1	6	4	1	1	3	5	7	1	7	3	4	4	3	
26	CE4	5	6	13	16	7	14	11	12	14	18	19	5	5	3	4	2	5	3		1	3	5	7	1	7	1	3	3	1	1
12	OL2	17	9	3	17	11	8	6	3	5	9	5	21	10	4	9	4	6	6	4	3	4	2	1	3	2	2	2	11	4	1
10	IFE	7	10	1	12	4	2	4	4	4	4	5	10	14	4	9	6	3	3	1	1	3	1		3	1	2	1	7	2	2
7	IoT	2	3		3	1		1	1	3	3	3	4	4	4	4	1		2		1				2	1			2		
8	ICT*	6	6		9	3	2	2	3	4	4	4	9	9	4	11	3	3	3	1	2		1		3	1	1		5	2	1
16	PSSP1	5	9	1	9	3	2	3	6	1	1	2	4	6	1	3	10	1	4	1	2	4	1	1	1	1	1	1	4	1	1
17	PSSP2	9	5	6	12	8	8	3	4	5	6	5	6	3		3	1	13	2	2	2	1	4	2		3		2	4	1	1
18	SL1	7	5	2	9	6	4	2	3	3	4	3	6	3	2	3	4	2	10	1	2	5		1	1	2	1	2	3	1	
19	SL2	4	2		3	5	2	2			1		4	1		1	1	2	1	5	1	1						1	2	2	1
20	SL3	3	3		2	3	1		1	1	1	1	3	1	1	2	2	2	2	1	4		1		1	1			1	1	
21	SL4	6	4	3	8	4	5	5	4	1	3	3	4	3			4	1	5	1		8		1		1	1	3	4	1	1
22	SL5	2	3	4	8	5	5	3	4	5	5	5	2	1		1	1	4			1		8	4	1	3		2	2	1	2
23	CE1	3	3	7	9	5	8	7	8	8	7	7	1				1	2	1			1	4	9		6	1	3	1	1	1
9	POC	2	2		2	1			1	1	1	1	3	3	2	3	1		1		1		1		3	1			2	1	1
25	CE3	4	3	6	7	5	7	5	8	8	7	7	2	1	1	1	1	3	2		1	1	3	6	1	8		3		1	1
11	OL1	1	2	1	4	1	2	3	3	1	3	1	2	2		1	1		1			1		1			5	1	1		
27	CE5	4	3	2	5	5	4	5	3	3	4	3	2	1			1	2	2	1		3	2	3		3	1	5	1		
13	OL3	9	7	1	12	5	2	7	3	2	4	3	11	7	2	5	4	4	3	2	1	4	2	1	2		1	1	14	3	3
14	TL1	4	4	2	6	4	3	2	2	2	3	1	4	2		2	1	1	1	2	1	1	1	1	1	1			3	8	3
15	TL2		3	1	4	2	1	2	2	1		1	1	2		1	1	1		1		1	2	1	1	1			3	3	5

Figure 11: Second Core/periphery analysis: whole sample

Driven by the schematic conceptual overview presented in Figure 1, the whole sample was analyzed applying the complete coding schema, as shown in Figure 12.

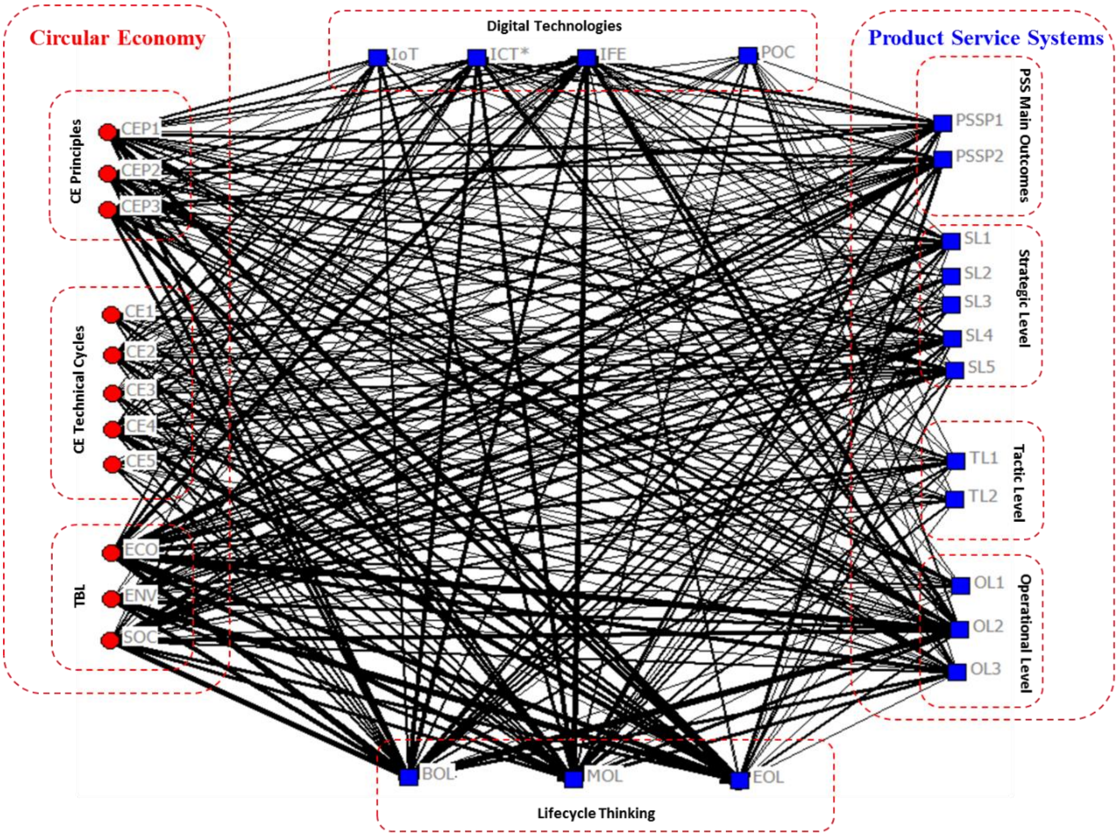

Figure 12: Whole Sample Network: PSS, Circular Economy and Health

Bridging the aspects elucidated by the samples separately, in figure 8 and 10, Figure 12 summarizes the main aspects proposed to be discussed. In fact, figure 12 is the translation of the interrelationship among the main themes of the whole sample (Figure 1).

It can be inferred that especially ICT (information and communication technologies) and IFE (information flow/exchange) play an important role throughout the lifecycle of any offered product or service, because they are responsible for translating the strategic and tactical intent into daily systematic actions. IoT (internet of things) and POC (point of care) individually are not leveraging substantial results, in the healthcare area yet based on the thickness of the connections and on the definition of the core class elements matrix from Figure 11.

The greatest density of connections is between TBL, lifecycle thinking and CE principles. It is noteworthy that EOL is more intensely connected with CE principles.

Circular economy technical cycles, in their turn, lack more connections within the consolidated management aspects from product service systems, bringing the reflection about the maturity level of the research and focus of each area. PSS (more developed) is focused on outcomes such as customer satisfaction and functional performance, with the economic dimension of sustainability more discussed within the healthcare literature. CE stimulates relatively new discussions, more focused on the conceptualization of solutions related to sustainability and circularity of material resources. It still lacks the managerial exploration that could be better developed by coupling CE with PSS business model.

8.5 Main findings and discussion

Returning to the research questions, the main findings are discussed based on the research results.

RQ 1: Which are the main topics relating the PSS business model to the healthcare context?

The research results into the literature on PSS and Health reached three main findings.

Finding 1: Healthcare faces general regulation, waste regulation and system complexity as primary challenges.

The healthcare sector is highly regulated, even more than other markets, aiming to mitigate risks related to the development of drugs or medical devices. Not only governmental authorities, but the industry itself are responsible for the regulations' definition. According to Mittermeyer *et al.,*(2011), however, "governmental policies clearly influence the market and its players in the health care sector", because "compliance to all applicable regulatory standards is mandatory for any provider of products or services to enter the market" (MITTERMEYER *et al,*.2011). Adding to it, there are challenging aspects regarding the circular economy. According to Lu *et al.*, (2015), bodies of environmental regulations are mostly weak institutions, especially in developing countries, that commonly subordinate environmental protection to economic interests when tradeoffs are identified. This engenders an effectiveness failure due to the lack of outside support from constituencies.

In its turn, waste regulation also hinders CE for PSS in healthcare. According to Alaranta and Turunen (2017),"regulation of residual materials is successful when it promotes reuse and recovery, reduces the detrimental health and environmental effects of the residual materials and reduces the costs and environmental harm incurred in obtaining the raw materials." However, promoting the reuse and recycling of residual materials can be disadvantageous, having a negative effect on the precautionary objectives of waste policy (ALARANTA; TURUNEN, 2017).

Winans *et al.,* (2017) suggest that "CE-related initiatives need to be well designed and evaluated regularly" through green engineering, for instance, promoting an investigation into the quality, process of used materials and product design, to support their reuse over time. Those initiatives require integrated bottom-up and top-down approaches to implementation and evaluation (VIANI; VACCARI; TUDOR, 2016), regulated by policy instruments, such as subsidies and tax incentives in short and long term aspects. “Without an evaluation framework or bottom-up support from the industry or the community, CE initiatives are not sustained.” (WINANS; KENDALL; DENG, 2017)

Especially in the developing countries, the reality is , “low levels of reuse, recycling and recovery of waste, shortage of advanced technology, significant waste disposal amounts and weak economic incentives are considered bottlenecks to sustainable development”(ILIĆ; NIKOLIĆ, 2016). Such related circular economy initiatives are unfortunately “constrained by a lack of regulation, incentive(s), and infrastructure required for resource exchange.” (WINANS; KENDALL; DENG, 2017). Adding to this context, according to Viani *et al.*, (2016) “the absence of potential buyers of recycled materials was one of the key obstacles to value recovery. The market appeared to be structured in a way to favour only big producers or suppliers of material” Some other barriers to sustained circularity can be mentioned, such as material flows (exceeding or not meeting demand), and transport and infrastructure limitation. In this case, the proximity of industries or resources available within the economic geography present relevant advantage (WINANS; KENDALL; DENG, 2017).

Alaranta and Turunen (2017) reinforce that “in some cases disposal may be the safest option from the traditional environmental protection point of view”. However, if the detrimental effects of obtaining a substitute material are considered, another conclusion might be reached, emphasizing the benefits of the circular economy.

Another issue according to Mittermeyer *et al.*, (2011), is “the high degree of specialisation in medical health care and increased complexity of technologies integration”. Compatibility between the devices in use in healthcare systems is therefore another challenge (FLORES-VAQUERO *et al.*, 2014).

Regarding complexity, diagnosis and treatments are becoming each time more patient-specific, which accelerates the trend to specialization, making the whole network of professionals even more complex due to the need for “integration”. Multi-dimensional products and services combination are increasingly required, for example, clinical workflow and training/consulting, drugs/devices and hospital infrastructure. Finally, there is a requirement in the business for a range of different professionals from clinicians, biologists, software IT specialists, mechanical engineers to architects in an integrated manner (MITTERMEYER *et al.* ,2011).

Finding 2: Future PSS business models focus on digital technologies and on wearable devices to monitor human health.

Most of the surveyed literature highlights software development and information flow either in a healthcare company (YIP AND JUHOLA, 2015) or in cases of point of care (POC) through personal devices, such as a telehealth system for diabetes management (FLORES-VAQUERO *et al.,* 2014) or glucometer cases (ADEOGUN *et al.,* 2010), which focus on the design of informatics.

According to Flores-Vaquero *et al.,* (2014) "systems that enable people with long-term conditions to manage their health at home could be the means towards cost-effective high-quality care services". These systems in order to monitor patients' conditions and transmit this information to a specialized central service, depend on sensor-equipped healthcare devices (point-of-care devices - POC). That would be the case of blood pressure monitoring (LEE *et al.,* 2015), glucometers (ADEOGUN *et al.*, 2010) or even smartphones with health applications connected to a tele health service through product service systems (FLORES-VAQUERO *et al.,*2014). "The interaction of health professionals with POCT devices therefore forms an important future domain of study, without which it is unlikely that the service-potential of POC-based PSS will be fully achieved." (ANDEOGUN *et al.,* 2010) The provision of efficient services based on POC technology depends, therefore, on the right integration with local and national health organizations, technological platforms to connect data and patients and health professionals ready to operate within the system, perfectly aware of the system constraints.

Therefore, some informatics gap needs to be addressed to properly implement a product service system (PSS) in such a manner that would change the traditional healthcare delivery model. The main issue is that "there is a general lack of informatics capabilities in existing healthcare devices; such devices do not record data in an exchangeable format and are difficult to interface with intermediary systems; this limits their use in telehealth applications."(FLORES-VAQUERO *et al.*, 2014).

Moreover, the design of the infrastructure to allow integrated solutions for healthcare (TILLMANN *et al.*, 2010) and tools to facilitate stakeholders' engagement in the informatics design for new product service systems (YIP *et al.,* 2014) are also discussed, as well as the modelling of information flow (DURUGBO *et al.,* 2012) and the assessment of a PSS in a collaborative network perspective (DURUGBO AND RIEDEL, 2013).

Thus, regarding digital technologies, they act as enablers between the inputs (PSS in healthcare) and outcomes (PSS performance evaluation and TBL). Digital technologies support the operationalization of PSS in healthcare, enabling design, tool development and high service complexity especially through the beginning and middle of life of a PSS. Digital technologies evolution in healthcare evidences a digital focus on better functional performance and better economic results, which the industry sector has surpassed a few years ago, enabling them to face sustainability challenges. Therefore, these main relations pointed out in Figure 8 suggest the following hypothesis about the moderating effect of digital technologies.

P1: The positive effect of PSS operational level (OP) on PSS outcomes (PSSP) and TBL is moderated by digital technologies such that the positive effect is greater when digital technologies are higher.

Finding 3: Drivers for change in healthcare reinforce the need for innovative research in the area

Most researchers emphasize the need for an in- depth dedication to the healthcare sector, because of main drivers that are changing the world's approach to health aspects. Table 6 synthesizes the main drivers on which researchers should focus in this sector.

Table 6: Drivers for change in the Healthcare Sector Approach

Drivers	**Definition**	**Reference**
Ageing of Population	Combination of longer life expectancy, declining fertility, and the progression through life of a large 'baby boom' generation, sometimes, known to need long-term care conditions	DUL ET AL.(2012); FLORES-VAQUERO ET AL (2014); BOEREMA ET AL (2017); YIP AND JUHOLA (2015)
Cultural Differences	Humans with different backgrounds; interdependencies between economies, industries and companies around the world, led by a culturally diverse workforce, with products and services consumed by an increasingly diverse set of customers in markets	TILLMANN AND FORMOSO (2010); DUL ET AL. (2012)
Lifestyle Habits	Improved access to information by wireless transfer of data and easier accessibility of information between sources and devices for each person to manage more actively his/her own health.	ADEOGUN AND ALCOCK(2010); SARANUMMI ET AL. (2006)
Automation and Technology - ICT	Provide more efficient healthcare services by means of technological devices, sensor-equipped healthcare devices (point-of-care (POC) devices), Internet of things (IoT) interconnections, Information Communication Technologies (ICT)	FLORES-VAQUERO ET AL (2014); ANDREONI ET AL (2012); YIP ET AL, (2014); SARANUMMI ET AL. (2006); DURUGBO AND RIEDEL (2013)
Economic Development Level	Economically advanced nations have increasingly outsourced manufacturing and service functions to economically developing countries in a global market perspective. The first, focusing on a service economy (including healthcare services), specially on the design of work systems for service production, and on the design of non-work systems (such as services) for customers and human-computer interactions. Requiring deep knowledge of complex social and cultural environments.	DUL ET AL. (2012); DRURY (2008)
Enhanced Competitiveness and the need for innovation	Need for new business strategies, innovating through the invention of new products and services, as well as new ways of producing these. Need for more efficient and flexible production processes, with short product delivery times, often resulting in intensive work and high -quality characteristics beyond functionality to gain commercial advantage.	DUL ET AL. (2012); DURUGBO AND RIEDEL (2013)

Sustainability	Sustainable products and services to improve the quality of life of people with health and social needs, environmental concerns related to product life cycle and disposability; combination of the people and profit dimensions of sustainability with social responsibility by optimizing both performance and well-being	ANDREONI ET AL, 2012; TILLMANN AND FORMOSO, 2010; DUL ET AL., 2012.
Stakeholders' Involvement	Those who have an interest in or are affected by the product service system, covering internal and external stakeholders: internally-the managers of marketing, manufacturing, and research and development (R&D) departments, and frontline employees; externally- the customers, suppliers, dealers, competitors, additional firms such as public or legal institutions and external research organizations.	YIP AND JUHOLA (2015); FREEMAN (2010); YIP ET AL (2014)
Perceived and provided Value Understanding	The perception of benefits achieved from acquiring a product in relation to the sacrifices associated with its acquisition; the effort of increasing the perceived benefits of a product or service when measured against the sacrifices associated with its purchase; value in the use of products is enhanced as additional services extend their traditional functionality	MONROE (1990); BAINES ET AL.(2007); TILLMANN AND FORMOSO (2010)
Complexity on service	The system in which healthcare infrastructure is developed is very complex, due to the large number of stakeholders involved. Because of the challenges for coordination and control and the conflicts in interest if potential competitors are within the same network	KREYE AND LEWIS (2015); TILLMANN AND FORMOSO (2010); DURUGBO AND RIEDEL (2013)
Government / Regulation	Local and national health organizations, Governmental regulatory authorities like the Food and Drug Administration (FDA) in the USA influence development costs for drugs, medical devices or services by setting the standards, requirements and restrictions for R&D; governmental policies clearly influence the market and its players in the health care sector.	ADEOGUN AND ALCOCK (2010); MITTERMEYER ET AL (2011).

RQ 2: Which are the main topics relating the circular economy to the PSS business model in the healthcare context?

Finding 4: Life Cycle Management and circularity opportunities should be further developed

Circularity, or in a broader sense, sustainability, unfortunately has not reached massive mobilization in the surveyed literature. Some still consider it a relatively new concern, although having the sector "a relevant environmental footprint because of the significant materials throughput, the hazardousness of certain wastes it generates and the energy intensive treatment necessary to manage them"(VIANI; VACCARI; TUDOR, 2016). Accounting for healthcare waste recycling (ALI; GENG, 2018) has been initially discussed. However, besides the production of a large amount of waste by the medical sector, "clinical challenges of safety and sterility that reuse of products or materials entail" (KANE; BAKKER; BALKENENDE, 2018) make the circular design principles even harder to apply. It can be inferred that due to "sterilization requirements, the device value and the organizational support structure around the device" (KANE; BAKKER; BALKENENDE, 2018) highly affect circular medical design.

According to Yang *et al.,*.(2017), "life cycle thinking seeks to identify possible solutions to improve goods and services by reducing resource use and environmental impacts throughout the entire product life cycle." The latter can be divided into three stages: beginning of life (BOL), middle of life (MOL), and end of life (EOL). During the BOL stage, the product is designed and manufactured; in the MOL stage , the product is distributed and used; in EOL the product is reprocessed (e.g., recycled, reused, remanufactured) and disposed.(WANG *et al.*,2011). The fact is that the whole life cycle of equipment and facilities must be considered to better integrate services, in a high performance perspective. (TILLMANN AND FORMOSO, 2010).

In the healthcare PSS research field, the design of systems (BOL) and the informatics based system use or electronic monitoring devices, (phm-prognostics and health management) (MOL) are more frequently researched, even though the mechanism behind the utilization of data for service value creation is nearly unknown (LIM *et al.*, 2018).

Finally, the information availability throughout the whole product's life cycle, from the design (BOL) to the end of its life are fundamental for successful CE principles deployment (JABBOUR et al., 2017). To reach industrial sustainability, it is necessary to understand how information flows and how data are collected and shared among the stakeholders (DESPEISSE et al., 2016), otherwise the integration between information management and sustainability strategies will keep the current status far from the ideal scenario (FIORINI; JABBOUR, 2017). In this context, the main relations among CE Technical Cycles, Life Cycle Management and performance pointed out in Figure 10 suggest the following hypothesis:

P2: CE Technical Cycles could be leveraged in healthcare if life cycle management were more intensely explored with an influence on performance aspects (business outcome and TBL).

Finding 5: Circularity challenges need innovative solutions.

The literature on product service systems covers an extensive business 'ecosystem', meaning a community of organizations, institutions and individuals that impact the enterprise and the enterprise's customers and suppliers, such as regulatory authorities, standard-setting bodies, the judiciary and educational and research institutions (TEECE, 2007). Among the main subjects, there are the extension of product scope to reach user needs; the services throughout the lifetime of a product; the generation of value through a robust system not only for final customers, but intermediate clients, other actors in the supply chain, and to society(TILLMANN; TZORTZOPOULOS; FORMOSO, 2010). Therefore, it is recognized that innovation and its supporting infrastructure have major impacts on competition (TEECE, 2007) and that " value generation is not simply focused on the end user; it also takes into account a wide variety of actors.” (TILLMANN; TZORTZOPOULOS; FORMOSO, 2010).

Considering this, examples of solutions still challenging to operationalize are suggested in the academic literature. For instance, according to Stahel (2013b) to accelerate the actions towards the circular economy, a tax system based on sustainability principles such as taxing non-renewable resources would be a powerful lever. That would change completely the geographical relationship among the ecosystem actors, prioritizing the distributed economy (JOHANSSON; KISCH; MIRATA, 2005) instead of the current global one.

According to Liedtke *et al.,* (2012), and aligned to Stahel (2007)“technological and social innovations can only be developed interactively by mirroring, explaining, and integrating emerging trends and consumer behavior”. In other words, changing existing systems and consumers' lifestyles though innovative and sustainable product service system, “capability reconciliation is required for all key partners of the project.”(BEHNAM; CAGLIANO; GRIJALVO, 2018)

At the operational level, the efficiency move is not something new. There were many moves to look at the waste with recycling possibilities. However, proper waste prevention is only possible with good design and good monitoring of industrial activities (BARTL, 2014)

Regarding healthcare infrastructure specifically, Tillmann *et al.,* (2010) suggest a shift to smaller, decentralized facilities to better control and program implementation; more focus on community and preventive services and greater reliance on information and communication technology, emphasizing the importance of developing intangible assets.

Finding 6: Stakeholders’ engagement is a precondition to business orchestration

According to Yip *et al.,* (2015), “the healthcare industry involves multiple stakeholders who regularly have conflicting interests.” This complex and interrelated structure of different stakeholders needs to be seen as long-term relationships, in which their communication contributes to a PSS’s functional performance. (BAINES et al., 2007) Therefore, long-term feedback during the product life cycle is not only expected, but mandatory (LEE AND PARK, 2015).

The exchange of information between procurement and waste management teams (or equivalent), has important consequences on whole life cost considerations, for instance. Aspects such as the dismantling of an instrument, the cost of waste treatment, etc. must be considered during the evaluation process at the time of purchase or offer (VIANI; VACCARI; TUDOR, 2016). At the same time, to ensure greater circularity, the manufacturer itself need to enable ease disassembly, so that upstream stakeholders can provide greater circularity. Procurement

staff should also have personal interest/knowledge to contribute to a more efficient end of life. Sometimes, regarding the whole perspective, the better and possible solution is, for instance, "the use of leased equipment to avoid disposal costs, the introduction of guidelines that the procurement department had to follow, and an evaluation and reward system to engage staff with more sustainable practices." (VIANI; VACCARI; TUDOR, 2016)
Related to product service systems, there is just one publication mentioning a sustainable framework within a life cycle approach (WANG *et al.*,2011). However, in the healthcare field, Kane *et al.*, (2018) are the first to bring the discussion on circularity into healthcare equipment. This shows the level of scarcity of research and publications in the area. The absence of publications combining the three research themes elucidates the distance between healthcare actions and academic literature.
Finding 7: Different countries face similar challenges
Implementing the circular economy actively requires the involvement of people in the process, instead of "being a passive representative of the throwaway culture"(GHISELLINI *et al*., 2014; VIANI; VACCARI; TUDOR., 2016) On the other hand, one great healthcare sector challenge is that "hazardous healthcare waste management concerns to the sterilization of potentially infectious and contagious devices." (VIANI; VACCARI; TUDOR, 2016)
It is still necessary to emphasize the end market dependence of medical devices manufacturers "to design instruments in a way to enable easy and quick disassembly" (VIANI; VACCARI; TUDOR, 2016) . However, a great obstacle is also the lack of potential buyers of those recycled materials, since the market seems to be structured in a manner that favours only great producers or suppliers of materials. In this sense, storage is also a challenge and a prerequisite in order to accumulate enough materials to make the collection and transportation costs effective. "Indeed, the level of segregation of the feedstock materials determines the quality and thus the price that can be commanded." (VIANI; VACCARI; TUDOR, 2016)
Therefore, within healthcare, at a more operational level, "countries face similar challenges, including limited communication between procurement and waste management staff, staff engagement, and end markets."(VIANI; VACCARI; TUDOR, 2016) . This brings discussion about the need for active green purchasing, dedicated waste management and effective segregation of waste to enhance sustainability.

8.6 Conclusions and Future Research Agenda

This paper contributes to academia through an in-depth analysis of the literature on PSS business model in the healthcare context, seeking to answer two research questions (RQs) proposed. It presents a conceptual framework exploring the intersection between PSS and the circular economy in the healthcare sector. Moreover, it explores the moderating effect of digital technologies and lifecycle management.

Seven main findings were explored, which are: First, healthcare faces general regulation, waste regulation and system complexity as primary challenges, bringing insights into the main issues in the area, regarding the level of services needed to be performed and the kind of regulatory problems faced. Second, future PSS business models focus on digital technologies and on wearable devices to monitor human health, which evidences the trends under development and the adaptations needed to take place on general behaviour. Third, drivers for change in healthcare reinforce the need for innovative research in the area, since human patterns are being modified, driven by digital technologies, new regulations, new lifestyle habits, sustainability issues and so on. Fourth, life cycle management and circularity opportunities should be further developed, especially because no evidence in the selected healthcare sample deals with this theme, leaving plenty of space to be explored regarding value opportunities from the sector's equipment management and activities. Fifth, circularity challenges need innovative solutions, which are worth any approach in any knowledge area, since an extra effort on the *status operandi* of usual linear business models are needed. The solutions are usually not evident, nor the gains equally directly realized, but the long-term thinking is not only imperative, but should turn into a competitive advantage sooner or later. Sixth, stakeholders' engagement is a precondition to business orchestration, so that the alignment of partnerships becomes mandatory to succeed in any move, softening the individual efforts towards a change to sustainability. Finally, seven different countries face similar challenges, so the economic development level should not be used as an excuse but faced as a usual pathway that needs to be travelled.

Based on these findings, two propositions are outlined and suggested for further research: (P1) The positive effect of PSS operational level (OP) on PSS outcomes (PSSP) and TBL is moderated by digital technologies such that the positive effect is greater when digital technologies are higher; (P2) CE technical cycles could be leveraged in healthcare if life cycle management were more intensely explored with an influence on performance aspects (business outcome and TBL). In addition, some important gaps in the literature stood out such as the lack of strategic perspective, and concerns regarding the end of life and environmental issues in the PSS field in the healthcare context, as well as the lack of connections in the CE research field with digital technologies aspects, functional performance and operational aspects such as design and monitoring, evidencing that they are almost two mutually exclusive samples that should connect to one another soon.

For the industry, the main implication is the systematized overview of the accomplished so far in the context of healthcare product/service systems and that the circularity approach in the field is not sufficiently consistent, although it should play an important role to successfully implement innovative business solutions in the near future. As an identified limitation, this research is based on search strings used in research engines (Web of Knowledge and Scopus), search filters and inclusion/exclusion criteria that may lead to taking out many important and well-known books, grey literature and proceedings papers. However, it can be considered a unique contribution in such a complex research area.

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APPENDIX A

Search Strings:	String Description	#Papers WoS	#Papers Scopus	WoSΩScopus	WoS+Scopus
Sample 1: PSS + Healthcare	Topic:("product-service system*" or "product service system*"or "product-service-system*" or "Industrial Product Service System" or "Integrated Product Service Engineering" or "Integrated product service offering") AND Topic: (health*) Refined by: Language: (ENGLISH) AND [excluding] Types of document: (PROCEEDINGS PAPER) Period: All years. Index: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH.	18	23	10	31
Sample 2: CE+Healthcare	Topic: ("circular econom*"or "clos* loop*"or "loop*") AND Topic: (health*) Refined by: Language: (ENGLISH) AND [excluding] Types of document: (PROCEEDINGS PAPER) Period: All years. Index: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH.	65	96	55	104
Total Sample		135			
Selected Sample		49			

Note: Some other search strings were used, but no relevant results were found, for instance: PSS+Healthcare+CE or even PSS+Healthcare+Sustainability, intended areas of discussion in this paper. Research done in December 2018.

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9 #P4: Who orchestrates a Product Service Systems (PSS)? An investigation of the Brazilian Health Business Ecosystem

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Abstract

Product Service Systems (PSS) in Healthcare has a great potential to leverage sustainability towards new business opportunities within a health business ecosystem. Yet, there are great barriers to overcome in one of the most complex and regulated systems of the world. Semi-structured interviews within 20 companies were performed and the relationships between health providers, manufacturing/service companies, regulatory agencies, government, digitalization companies, and hospitals/clinics were mapped and in-depth explored. Among the findings, this paper presents the healthcare business ecosystem configuration with their main roles through the lenses of PSS life cycle stages. The main aspects of each stage are discussed within each PSS business modality: product-oriented, result-oriented and use-oriented, emphasizing sustainability aspects in emergent business opportunities influenced by the Business Ecosystem. Finally, a framework shows the integration of the main stakeholders' groups and the health business ecosystem with hindering and fostering aspects to more sustainable health PSS business. This research contributes to broadening the understanding of the challenges regarding PSS implementation towards sustainability and the healthcare business ecosystem influence, proposing future pathways to overcome them.

Keywords: Healthcare Business Ecosystem; Product Service Systems; Lifecycle Thinking.

9.1 Introduction

The application of a more sustainable Product Service Systems (PSS) in developing countries is still an underexplored area since they have to face the challenge of balancing economic growth with social and environmental considerations (NNOROM;

OSIBANJO, 2008). According to Shokohyar et al. (2014), many developing countries are consumers of imported products from other countries, especially high tech embedded products/equipment. Such a situation has as a consequence that only the consumption and the end of life (EOL) phases occur in these countries. In this circumstance, theoretically, the manufacturers and their representations tend to introduce more sustainable PSS schemes to manage usage and EOL phases. Such as the case of medical equipment in Brazil.

Addressing economic, environmental and social aspects through integration is a key aspect of a PSS implementation. Because companies that offer and develop PSS are often moving from the traditional manufacturing model (that aims at selling products as the main strategy) towards the offer of an integrated solution "a marketable set of products and services capable of jointly fulfilling a user's need" (MONT, 2002a). As a consequence, PSS can be described as " the result of a strategy that seeks to optimize the performance of a system through supporting users and other stakeholders in the post-production life cycle stages" (Kjaer et al., 2016a). In synthesis, PSS seeks to improve the use phase through different services such as intensified use, improved availability of the product (through intensive maintenance processes) or through multiple users of the same product (GRÖNROOS, 2011).

Product Service Systems (PSS) are often categorized into three types (Wang et al., 2011; Tukker, 2004): (i) product-oriented (PO), the physical asset is fundamental and the customer possess its ownership, but the manufacturer provides additional services, e.g. maintenance services or consultancy (after-sales); (ii) use-oriented (UO), the asset's use is provided for a certain time to the customer, and the ownership belongs to the manufacturer, e.g. bike-sharing or equipment renting; and (iii) result-oriented (RO) the asset ownership belong to the manufacturer and the business corresponds to the sale of a certain level of performance, e.g. "pay-per-use", energy management services, healthcare laboratory equipment leasing. According to this gradation, the provider's stewardship is gradually extended, to cover more life cycle stages elements, such as the use stage and end-of-life (Baines et al., 2007, Kjaer et al., 2016a). Moreover, stakeholder networks and strategic partnership are mandatory for PSS implementation (VEZZOLI et al., 2015).

Considering this latent potential of PSSs, it is mandatory to understand how the Business Ecosystem (BE) configuration can interlock the stakeholders "to boost their solutions to a more sustainable level" (GUZZO et al., 2019). In this sense, the multiple sectors that affect health (which are frequently driven by a variety of stakeholder and interest groups) have both, different cultures, values, and vocabularies and also usually lack experience working together, which can also likely hinder partnership and collaboration (DELOITTE, 2019). According to Amor et al. (2018) such multi-actor perspective, different from the usual one-sided PSS evaluation (customer point of view or provider perspective) is needed to manage the economic, organizational and new social infrastructure transitions to support the desired environmentally benign performance. To reach this intent, the PSS network value must be intensified and the policymakers need to be added into this multi-actor perspective (MONT, 2002b).

The Healthcare business ecosystem has undergone profound changes and new business paradigms are making the Brazilian healthcare market "one of the most promising and attractive in the world" (PWC BRASIL, 2013). Nevertheless, companies of the medical diagnostics sector are facing great challenges due to the need for increasing their exam capacity and their market share, because large competing conglomerates tend to predominate in the health sector and the bargaining power is held basically by health insurance companies (Prieto and Carvalho, 2011), transforming the price per exams, metaphorically, in commodities. That is why the business ecosystem concept comes into the scene.

According to Williamson and De Meyer (2012), ecosystem strategies allow organizations to coordinate "difficult-to-manage relationships with many different types of parties" as well as "the exchange of knowledge between many, mutually dependent partners", which fits into the challenges of improving healthcare PSS. Furthermore, there is also a gap in the research on the "specific links between BEs and PSS development" (Pereira et al., 2019). Most of all, healthcare is often mentioned as an area in which PSS possess great potential (Mittermeyer et al., 2011), yet, studies on this topic are still very scant (XING; RAPACCINI; VISINTIN, 2017). Could the business ecosystem (BE) somehow influence the conquering of better sustainability-related outcomes in a PSS?

This work aims to contribute in this conjunction of ideas, by enlightening sustainability possibilities in PSS business models developed in the healthcare sector. We intend to bring more understanding of the business ecosystem influence through the moderating effect of the life cycle thinking during the PSS orchestration. Thus, the main research question leading this paper is:

Who orchestrates a product service system (PSS) in the health business ecosystem to make it healthier and more sustainable?

We perform the investigation through an inductive and exploratory research design, presenting the main findings of 20 case studies and 57 interviewees within the Brazilian healthcare sector. Findings from the research suggest that the dynamic of the BEs might encourage the sector modernization, the development of new business models, and even different sustainability trajectories, according to the kind of PSS developed. Which conducts a second research question:

How does the business ecosystem (BE) affect the PSS configuration in terms of favouring more sustainable actions?

Some previous findings suggest that in RO-PSS, the trajectory is controlled and fully regulated since large companies with headquarters abroad need both to protect their image and act according to matrix guidelines for sustainability. For UO and PO-PSS, new business solutions emerge from the second-hand equipment market to make products even more profitable, either by extending their life cycle through negotiations conducted in the parallel market or by contracting non-regulated maintenance services to save economic resources. In both trajectories, the sector is improving in sustainability related-outcomes, however, different drivers conduct the moves and policymakers are fairly far from orchestrating the BE through regulation.

This paper comprises six sections. Section 2 offers an overview of the theoretical background. Section 3 describes the methodological approach of this research, while Sections 4 and 5 present and discuss the findings respectively. Finally, Section 6 outlines the conclusions of this study.

9.2 Literature Background

9.2.1 PSS Business Model and the Life Cycle Stages

Product Service Systems (PSS) is a business strategy of providing integrated products and services to satisfy a customer's need (MONT, 2002a). The key idea behind PSS is that consumers do not demand products per se, but are seeking the utility provided by products and services (BAINES et al., 2007), which must take into account the impacts over the entire life-cycle of a service or product. One of the many values added of PSS lies in their potential to decouple consumption from economic growth (KJAER; PIGOSSO, 2018), as they offer the possibility of meeting more needs with lower material and energy requirements (GEET et al., 2015). Despite the fact that services have the possibility to generate higher margins than the products itself, managers might not be fully convinced, since PSS opportunities are far from being properly explored (Gebauer and Fleisch, 2007; Fain et al., 2018).

Adding to that, it is noteworthy that the identification of the changes required in the business of companies adopting PSS is one of their main challenges, which derive from the difference between the PSS and the traditional way of developing and selling products. Since they are distinct business from each other, the business model concept application emerges as mandatory (BARQUET et al., 2013). According to Osterwalder et al. (2005), business models are the representation of the business logic definition regarding the companies' strategies, operations, and relationships.

Besides, the relationship between the consumer and the manufacturer play a key role in the sustainability of a PSS, moreover, all partners in the extended value creation network should collaborate in coordination avoiding insufficient consideration of the influences of products and services mutually. For proper PSS development, the life cycle oriented management of product and service is fundamental (Wang et al., 2011). This requires different ways of thinking and working throughout the product design stage and procurement process and supply chains, continuing through to the end of the products life, acquiring experience on how to encompass all important aspects of the life-cycle and putting the adequate organizational and business models in place (GEET et al., 2015). In this context, the ability to address economic, environmental and social aspects through integration is a key aspect in the development of successful business models (Lozano, 2008).

Though experts have different opinions on the definition of PSS (ANNARELLI; BATTISTELLA; NONINO, 2016), most of them assume the same PSS categorization (Tukker, 2004), or business models (REIM; PARIDA; ÖRTQVIST, 2015): product-oriented PSS; use-oriented PSS and result-oriented PSS, according to the evolution of PSS (Wang et al., 2011). According to Baines et al (2007): the first (PO), has its focus in selling a product that comes with extra services. The second (UO) the product is still central and not sold to the customer; however, the use or availability is offered for a specific time in which the provider is paid periodically. The third (RO) the customer pays for the agreed with the supplier upon the result. In those categories, the product lifecycle monitoring plays a fundamental role.

The product lifecycle is composed of three main phases (Jun et al., 2007; Wuest and Wellsandt, 2016): (1)beginning of life (BOL), which includes design, production and logistics (distribution); (2) middle of life (MOL), including use, service and maintenance; and (3) end of life (EOL), which includes reverse logistics (collecting), remanufacturing (disassembly, refurbishment, reassembly, etc.), reuse, recycle, and disposal. In this sense, after selling a product, in PO-PSS business model, for instance, manufacturers do not monitor any products information during the consumption period, besides warranty and eventual maintenance.

However, customer use phase decisions regarding a product "on whether to repair, pass on or throw away due to post-warranty maintenance costs and product functionality" diminishes product useful life, generating more waste (SHOKOHYAR; MANSOUR; KARIMI, 2014). Connected to this aspects, technology approach here is seen not only as a source of growth, providing information throughout the whole life cycle, but also helps maintain competitive balance and provide the commercial incentives that can help align supplier interests with those of the environment (FAIN; WAGNER; KAY, 2018).

Important to note that PSS is not automatically greener and can sometimes have an even greater environmental impact than traditional models (Kjaer et al., 2016b). To deliver sustainability benefits it is, therefore, mandatory to conquer more knowledge about the ways PSS can be organized (in all three levels: social, environmental and economic) besides taking into consideration total life cost requirements (GEET et al., 2015).

Regulations and standards in the policy domain are becoming increasingly stringent and can be seen as an interesting source of competitive advantage. Companies that use life-cycle thinking and are significantly ahead of regulatory requirements may influence on regulation under development for instance. The legislation still needs to stimulate more accountable along the whole product life-cycle, from the raw materials and resources acquisition, through production, recycling, reuse and final waste management (NNOROM; OSIBANJO, 2008). Governments can also help to expand business opportunities by developing PSS-related policies and making them part of existing procurement policies (WITJES; LOZANO, 2016).

9.2.2 Healthcare Business Ecosystem towards sustainability

The concept of ecosystems proposed by Moore (1996) in his seminal article on business ecosystems has helped scholars (e.g., IANSITI; LEVIEN, 2004; ADNER; KAPOOR, 2010; ADNER, 2017) to more broadly understand the mechanisms of cooperation and collaboration used by organizations (GOMES et al., 2018) to jointly present more attractive offerings (BOSCH ; OLSSON, 2018) and moreover to ensure sustainable benefits (PARIDA et al., 2019).

In this sense, ecosystems are considered "the new way of operating" and "the ability to strategically reposition oneself to increase or shift power balance is becoming key for competitive advantage” (BOSCH; OLSSON, 2018) and also for ensure the creation of sustainable benefits, that “transcending the value chain relationships” (PARIDA et al., 2019), since it requires the alignment of interests and incentives across ecosystem stakeholders (PARIDA et al., 2015; PARIDA et al., 2019).

However, there are a number of pitfalls when stakeholders “trying to realize strategical changes in their ecosystems” (BOSCH; OLSSON, 2018), especially in complex scenarios where there is a huge interdependence between multiple actors to achieve objectives, as occurs in the articulations between organizations within the PSSs (AMOR et al., 2018; PEREIRA et al., 2019). Bosch and Olsson (2018) highlight that some of these pitfalls occur “when powerful ecosystem partners assume that they understand what others regard as value-adding without validating their assumptions”, “when companies overlook the effort required to align interests”, or “when companies disrupt an ecosystem assuming that all partners can change direction at the same time”.

To avoid some of these pitfalls it is important to map the stakeholders (actors) and their bundle of moves (HANNA ; EISENHARDT, 2018), considering their interdependent relationship in the business ecosystem (ADNER, 2017). Understand the stakeholder's interests could allow organizations to coordinate these “difficult-to-manage relationships with many different types of parties”, to “successfully harness the power” of them (WILLIAMSON; DE MEYER, 2012).

9.2.3 The Brazilian Healthcare Business Ecosystem

Brazil is the largest healthcare market in Latin America and spends 9.1% of its GDP in healthcare (EMBASSIES, 2018). The sector is divided between private and state with the public healthcare accounting for approximately 45% of total health expenditure in 2014 (MARKET RESEARCH FUTURE, 2018). From circa 6,500 hospitals in the country, 70% are private. Local manufacturing is limited to a few consumables making the country extremely dependent on imports, which account for approximately 75% of the total market for medical devices. The healthcare regional availability in Brazil presents extreme social and economic differentiation of the Brazilian population, as well as poor healthcare in its vast rural areas (PWC BRASIL, 2013). Note that it is the only country in the world to have a system of free and universal public health (taxes paid by Brazilians cover all types of consultations and treatments offered by Unified Health System (SUS) without charging any additional to the user).

The SUS is a fundamental structure for healthcare in Brazil since many Brazilians cannot access the private system. However, private-sector spending is greater than that of the government. In 2009, the government allocated around R$ 79 billion ($ 39 billion) to SUS, while the private network contributed approximately R$ 91 billion ($ 45 billion). In Brazil, providing a private health plan is one of the benefits most valued by employees. Therefore, 63% of contractors have collective business plans and the terms, including price adjustments, are established by agreement between the operator and the plan beneficiaries (ANS, 2017). Also, from 2006 to 2016, the penetration of private insurance throughout Brazil's total population increased from 19.9% to 23.2%. The implication is that, with more individuals insured, the use of diagnostic services also increases (GONZALEZ, 2017).

"Brazilian healthcare market is complex, asymmetric, fragmented, with high demand, and government involvement/support" (PWC BRASIL, 2013), which creates "big opportunities for the largest players to continue to consolidate" (GONZALEZ, 2017). Still, there is a long list of gaps commonly found in most of the companies, public or private, profit or non-profit organizations which are issues such as cost reduction, process review, upgrade in the management information system, training of medical and administrative teams, updating of equipment, etc. These add huge discrepancies in the healthcare industry in terms of facilities, technology, and management (PWC BRASIL, 2013). Especially because, in line with the global trend, industry costs in Brazil are also on the rise, mainly due to the ongoing technological developments and human longevity, turning operators more concerned with improving their management and operational control in order to remain profitable in a highly competitive environment.

The sector faces a paradox, technological advances that require high investments are needed, but the pressure to reduce costs is huge. "In this context, the market tends to be dominated by large competing conglomerates, where investments can have a counterpart in gains of scale" (PRIETO; CARVALHO, 2011). For instance, private laboratories are a significant niche with global revenues of R$ 20.2 billion/year (around US$ 10 billion), and due to these groups' high-profit margins, this is the healthcare segment with most merger and acquisition (M & A) activity (PWC BRASIL, 2013).

Regarding digital technologies, currently, the market for medical devices is rising for factors such as advancements in connectivity and processing power of devices, cloud integration, demand for early detection and non-invasive therapies (cancer example), development of stronger biocompatible materials growth of healthcare mobile applications, growing awareness and spread of information technology (IT) (MARKET RESEARCH FUTURE, 2018). The adoption of new technology stimulates especially the diagnostic market, which performs mostly with imported inputs. In healthcare, innovations do not simply replace existing treatments, but rather enhance the selection of products and services available to consumers (GONZALEZ, 2017).

Following Table 1 summarizes the main subjects that ground this research.

Table 1 – Summary of Literature Background.

Main Subject	**References**	**Specific Themes**	**Synthesis**
Lifecycle	Jun et al. (2007); Wang et al. (2011); Kjaer et al., (2016a)	Beginning of Life Middle of Life End of Life	Each lifecycle stage compass specific activities, different levels of interdependency and engagement intensity among stakeholders. PSS migrates the “life cycle gate” to post-production phases, intensifying provider stewardship to MOL and EOL stages.
PSS Business Model	Tukker (2004); Wang et al (2011); Annareli et al (2016); Pereira et al., (2019); Mittermeyer et al. (2011)	Competitive Strategy Business Model Government/Regulation	PSS strategic level represents the different approaches from the business model itself, from PSS contractual aspects to competitive strategy aspects, new business opportunities, digitalization strategies, government incentives, regulation influence, and stakeholders’ network.
Business Ecosystem	Iansiti and Levien (2004); Moore (1996); Parida et al (2019); Adner and Kapoor (2010); Adner (2017); Williamson and De Meyer (2012); Hannah and Eisenhardt, (2018)	Players Interdependency Multi actors relationship	The BE is considered a group of multiple stakeholders (organizations and individuals) configuring an economic community that interacts with interdependency, producing goods and services to customers, who are also the “group” members. There is usually a leader that orchestrate most stakeholders to make each one take on their role.

9.3 Research Methods

Given the scarce empirical research and the exploratory nature of the research question on the business ecosystem of healthcare product service systems (PEREIRA; KREYE; CARVALHO, 2019) and specially within the circular economy technical cycles aspects (GUZZO et al., 2019), multiple case studies are particularly useful as suggested by several authors (Eisenhardt, 1989; Eisenhardt and Graebner, 2007; Yin, 2013). Despite the issue of generalisability, case studies are specially indicated for in-depth analysis and investigation of complex social phenomena such as the healthcare area, which is a very context-specific research field, allowing a holistic analysis of contemporary aspects obtained when the boundary of the phenomenon of interest is unclear (YIN, 2013).

9.3.1 Sampling and data collection

Theoretical sampling is performed, rather than choosing a representative sample of cases (EISENHARDT; GRAEBNER, 2007) getting a broad variety of perspectives in the healthcare product service system field.

The unity of analysis is the business ecosystem itself, the interdependent relationship between the multiple actors (ADNER, 2017), providing multiple perspectives. Besides, the investigation of several healthcare solution providers and the bundle of interdependent stakeholders moves (HANNAH; EISENHARDT, 2018), offered the advantage of selecting a diversity of perspectives in the field, bringing new insights (EISENHARDT, 1989).

The selection criteria were guided by choosing different organizations with distinct roles and perspectives in the healthcare ecosystem, such as equipment and materials suppliers, hospitals and clinics, hardware, middleware and software developers, research community, governmental organizations, regulatory agencies, healthcare providers, design and consultant companies, among others that compose the healthcare stakeholders' network. Note that special attention was given to diagnostics healthcare equipment (laboratories and imaging).

The sample provides a considerable diversity of business models, encompassing companies B2B (business-to-business) and B2C (business-to-consumer) based in Brazil; such as service providers and manufacturers; small, medium and large organizations. The number of employees was the main criteria for classifying the company size into: small (less than 10), medium (between 11 and 1.000) and large (more than 1.000). Thus, we present twenty case studies with different levels of the relationship among each other within the same healthcare business ecosystem. Table 2 shows an overview of the organizations and interviewees roles that participated in this research.

The combination of primary data collection (semi-structured interviews) and other information sources (public and internal documents) from twenty different organizations, allows to evidence contrasts and consonances (VOSS; TSIKRIKTSIS; FROHLICH, 2002) among the cases, improving understanding on the area (SIGGELKOW, 2007) and also helping to mitigate the bias that multiple case studies may impose (YIN, 2013).

The main data sources are semi-structured interviews, which were recorded, once agreed by the interviewee, transcribed and validated for further analysis, combined with the analysis of a variety of documents published by the companies itself or by third parties (grey literature).

The literature analysis described in the previous section grounded the research instrument aligned with the theoretical background (Table 1), which allowed us to trace different aspects of organizations embedded in the business ecosystem while identifying the interdependency and challenges in the healthcare field.

The interviews' instrument was divided into three parts (BOL, MOL and EOL) with the objective of "photographing" the most evident arrangements between the stakeholders within each main phase of a PSS in the healthcare business ecosystem. Besides, the following aspects oriented the investigation: PSS Business Model and Business Ecosystem, bridging those research areas within the healthcare diagnostics equipment (imaging and laboratories) empirical research (see Table 1).

The questionnaire was developed following the three-lifecycle stages logic. The first part, BOL, was related to PSS business model elements (design, service modularity, stakeholders' engagement). The second part, MOL, was focused on the PSS operationalization, digital technologies applied to the PSS business model and routine relationships between stakeholders in terms of main PSS outcomes, service complexity, digital PSS enablers. While the third, EOL, we asked about final equipment procedures in terms of sustainable PSS opportunities bridging this research area with the BE.

This research instrument was tested in three pilot interviews with two PSS researchers and a practitioner from a PSS provider company. After this step, adjustments were performed, such as the order of some questions and the used terms to ensure assertiveness. After the instrument definition, the field research was started (EISENHARDT, 1989; SIMMONS, 2009). At least one key-informant of each case study was interviewed, altogether 57 interviewees (see Table 2). The main selection criterion for each interviewee was a broader business knowledge level (not limited to his/her own department). Most hold leadership position as managers, or in the case of small-sized companies, are CEOs. Besides, multiple providers and a diversity of stakeholders were chosen as different levels of complexity, in this context, can impose more difficulty to the different organizations, depending on their knowledge and experience.

Table 2 - Overview of case studies.

Case	B2B/ B2C	Type	Size	Employees	Nº of Interviews	Interviewees' Roles	Business Reference
#A	B2B B2C	Service	M	>100	1	**CEO– Physician**	Imaging Diagnostic Clinic
#B	B2B B2C	Service	L	> 22.000	8	Clinical Engineering Director; **Clinical Engineering Manager;** Imaging Equipment Manager; **Contracts Manager;** Laboratory Physician /Manager; **Maintenance Manager;** Equipment Disposal Manager; **Waste Disposal/Quality Manager**	Largest Latin America Hospital Complex
#C	B2B B2C	Service	L	>15.000	8	Innovation Director; **Laboratory Physician /Manager;** Innovation Physician/Manager; **Infrastructure Manager;** Clinical Engineering Manager; **Value Management Office Physician /Manager;** Procurement Manager; **Imaging Equipment Manager**	Best Latin America Hospital Complex
#D	B2B	Manufacturing /Service	L	>10.000	5	Service Operations Manager-Latin America; **Project/Product Manager-Latin America;** Services Director-Latin America; **Product/Service Quality Manager-Latin America;** Service Manager- Brazil	Imaging Diagnostics Manufacturer – Latin |America Market share leader
#E	B2B	Manufacturing /Service	S	5	1	**Executive Director**	Digital Technology – ICT Enabler
#F	B2B B2C	Service	M	>3.000	3	Clinical Diagnostics Physician /Manager; **Imaging Equipment Physician /Manager;** Waste Disposal / Quality Manager	Oldest High Complexity Public/Private Hospital in Brazil
#G	B2B	Service	M	>300	3	**Latin America Director;** Project Engineer Account Leader; **Lead Business Manager**	Consulting-Hospital infrastructure implantation
#H	B2B B2C	Service	M	>2.000	1	Executive Director	Private Hospital – integrated ICT implantation reference
#I	B2B B2C	Service	M	>20	2	**CEO – Physician**; Services Manager	Imaging Diagnostics Clinic
#J	B2B	Manufacturing /Service	S	10	1	**Executive Director-CEO**	Digital Technology – ICT Enabler
#K	B2B	Manufacturing /Service	L	>2.500	2	Lead Account Manager; **Maintenance Manager**	Health Manufacturer – Nephrology PSS equipment
#L	B2B	Services	M	>100	2	CEO; **Project Engineer Account Leader**	Consulting-Hospital infrastructure implantation
#M	B2B	Manufacturing /Service	M	>400	1	Service Director	Imaging Diagnostics Manufacturer - Large player in Latin America
#N	B2B	Manufacturing /Service	L	>1.200	3	**Account Manager Leader;** Repair Shop Manager; **Regulatory Affairs Manager**	Laboratory Diagnostics Manufacturer –

							Large player in Latin America
#O	B2B	Manufactu ring /Service	L	>45.000	5	Head of Enterprise Service Solutions; **Service Director;** Customer Service Engineer Manager; **Products Manager;** Sales Manager	Laboratory Diagnostics Manufacturer – Large player in Latin America
#P	B2B	Governme ntal Service	M	>10	2	**Auction Manager;** Warehouse General-Manager	Equipment EOL Procedures
#Q	B2B B2C	Service	L	>19.000	4	**Production Manager – Director;** Facilities Manager; **Innovation Manager – Director;** Procurement Manager - Director	Largest Conglomerate of Laboratory Diagnostics Organizations in Latin America
#R	B2B	Regulator y Agency	L	>2.000	3	**Technology and Health Products General-Manager;** Implantable Materials Coordinator; **Clinical Research Coordinator**	Brazilian Medical Regulation Institute
#S	B2B	Service	M	>100	1	Market General-Manager	Manufacturers' Waste Management Company
#T	B2B	Service	M	>10	1	**Executive Director**	Digital Technology – ICT Enabler

9.3.2 Data Analysis

The content analysis was performed on the transcribed interviews which were coded and further explored (frequency counts and cross-tabulations) grounding the interpretation of results (DURIAU; REGER; PFARRER, 2007). A computer-aided approach was used through the software NVIVO (BAZELEY; JACKSON, 2013), to perform the coding and further in-depth analysis of interview data, enabling insights by the aggregation of information towards the most relevant aspects. The data were worked from the ground up (YIN, 2013). When the data were examined, many concepts emerged, following the grounded theory methodology proposed by Corbin and Strauss (1996), since it is an exploratory approach and no explicit testable hypotheses exist.

The coding of data followed the stages of each interview and included three blocks of themes, according to Table 1 derived from the literature background. It started with general aspects of the lifecycle approach (BOL, MOL and EOL) and, in sequence, the business ecosystem perspective and its actors influence in the PSS development, through the strategic aspects of the stakeholders' orchestration lenses. The latter, for being strongly context-dependent, affects directly the business models. The case results were then triangulated with the literature and a framework is proposed combining insights from the case studies and the literature analysis.

9.4 Research Results and Discussion

To show an overview of such a complex environment and eventually develop improvements in understanding, as suggested by Eisenhardt and Graebner (2007, p. 29), it is appropriate to summarize evidence in sections in which every part of the theory is demonstrated by evidence from at least some of the cases, but also providing multiple perspectives from the different actors were directly quoted to clarify the understanding.

9.4.1 Mapping the ecosystem interaction

9.4.1.1 BOL-Beginning of Life

The BOL corresponds to the lifecycle phase where product/service concept is generated and its physical model is realized (JUN; KIRITSIS; XIROUCHAKIS, 2007) This study focus diagnostics equipment on the two opposite extreme categories of product service systems - product-oriented (imaging equipment) and result-oriented (laboratories equipment). Imaging equipment is usually purchased, with complementary modules of services varying from low (basic services, such as warranty and corrective maintenance) to high service complexity (software updates, after office hour support, upgradability agreements and others) (KREYE *et al.*, 2015). The first does not need frequent consumables to perform diagnostics; the second needs a great volume of them (usually different kinds of reagents). However, the movement of the ecosystem during the health equipment beginning of life (BOL) are practically the same. Internally to the manufacturer, the planning, designing and eventually assemblage happens, while negotiations are performed with the contractor (see, figure 1 for a schematic representation of contractor's business decisions). Parallel to those processes, many other stakeholders are being involved (see figure 4 for schematic stakeholders' network).

There are three types of business contracts in terms of diagnostic equipment represented in Figure 1. They can be purchased (PO-PSS – imaging equipment), go through a lending process (RO-PSS – laboratories equipment), or can be rented (UO-PSS – not specific equipment).

Figure 1 shows that. once the need of new equipment is detected, which can be stimulated by a manufacturer's special offer, by a contractor's call of proposals or by a second-hand market proposal, the discussion about equipment design and contractual issues start. To this study, specific details on PSS design and contracts agreements will not be further discussed. To generalize the approach to any healthcare equipment, three modalities are shown. The first is the purchase, in which the contractor will own the equipment and the PO-PSS will be performed by the original manufacturer, through complementary services offers such as warranty period, maintenance agreements, and further services details. In the case of a RO-PSS, the lending contract is made and the manufacturer-contractor relationship is more complex, as well as contractual agreements and definitions regarding number and type of results needed monthly, equipment availability, level of consumables contracted, managerial responsibilities, penalties for each occasional misalignment, upgradability aspects and so on.

Due to the number of technical decisions, responsibilities definitions and penalty terms that the contract must contain, the contractual part of the RO-PSS is demanding. In general, contracts' definitions involve many internal and external stakeholders with different roles in the ecosystem, according to *Clinical Engineering Director – Case #B*: "[…] *we take the needs of the clinical body; they say what equipment they want, which clinical requirement. We research which equipment offers that performance […]and we make a harmonized technical specification* […]. *So, it's done with many hands, clinical engineering, nursing, medical group, purchasing department, manufacturers consultancy ... even IT department as well* [...]. The amount of direct and indirect stakeholders is the main characteristics of such contracts.

Besides, in lending contracts (RO-PSS), the touchpoints between manufacturer and contractor are more frequent, differently from the sporadic touchpoints within the purchasing contract. In the case of UO-PSS, the rent contract is performed, usually for a short term, in which performance and general aspects of maintenance are defined in contractual agreements. In imaging equipment, the purchasing contract modality (PO-PSS) is the most used. However, also depending on the contractor business strategy, and internal arrangement to deal with operational issues, these stablished business modalities may shift. Specific situations also influence the kind of business contracts chosen. "*The rent pretty much applies to certain technologies that you need for only six months, a month, or need for today. (For instance,) You're going to have surgery, you do not have that Laser… Rent it, (when) it's finished, it's back, there may be another one, a month from now, okay, rent it. But renting is not a good choice when you know you will need that equipment all your life, or at least for ten years*" (*Imaging Equipment Manager - Case #C*).

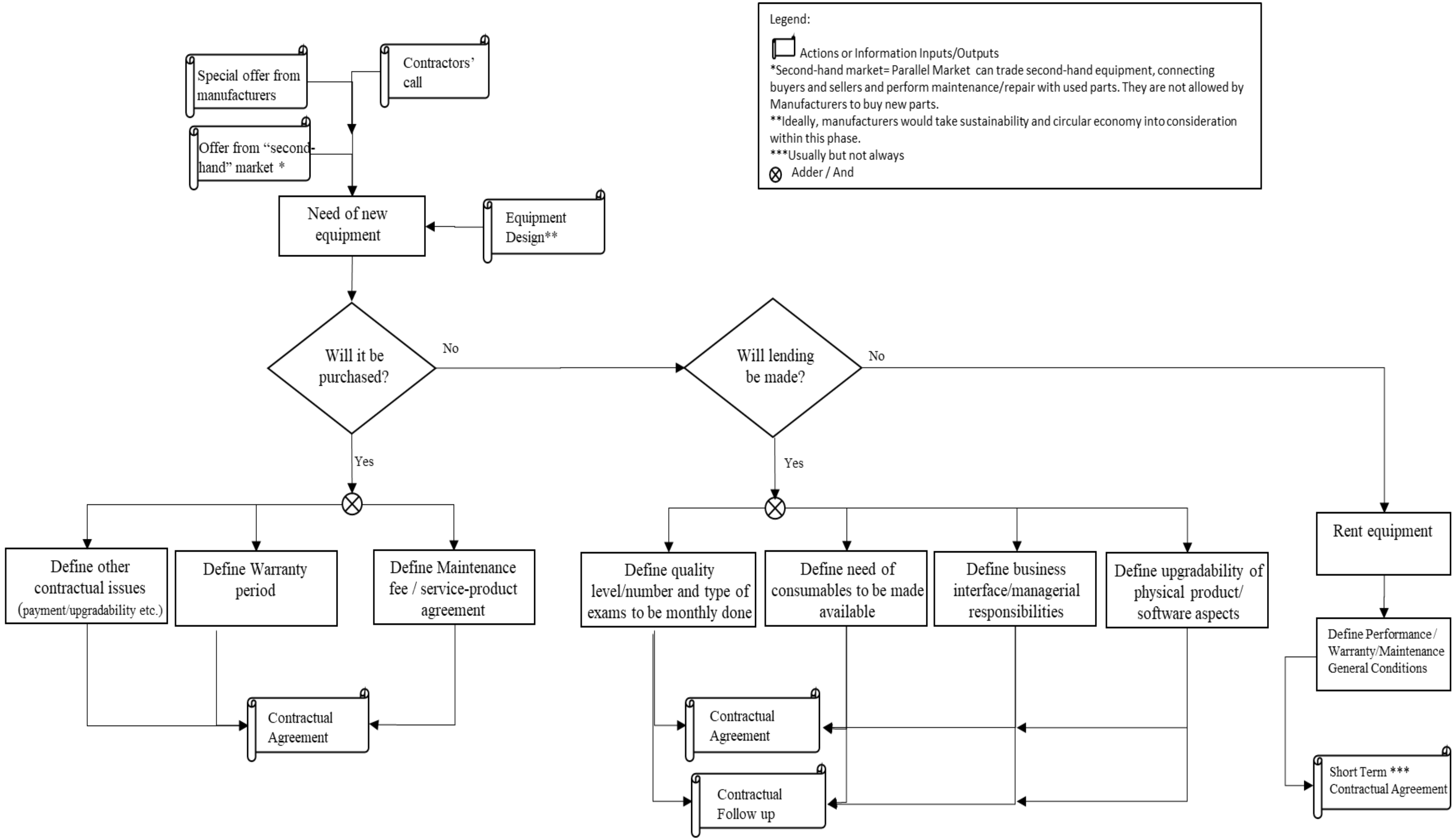

Figure 1: Healthcare Equipment – BOL Process (in terms of contractor decisions).

During the BOL negotiation, either for acquisition or lending process, one aspect about the registration at a Brazilian regulatory agency (Anvisa) is considered fundamental to diminish the risks. "*Registration at Anvisa actually includes everything we need to verify as customers. Because Anvisa also asks for the test of Inmetro, Anvisa already charges all the manufacturers' documentation we need to check, even the environmental aspects* […] *Anvisa's registration represents more safety for us" (Imaging Equipment Manager – Case #C).*

The intensity of the interdependency between stakeholders in the BOL phase in mostly centered in the design process either of the product/equipment or the service package to attend the customers' demand. As previously mentioned, some regulatory issues stand out, related to Anvisa's health product/equipment authorization, which represents a whole complex system of numerous certifications through professional associations and national institutions. Regarding environmental aspects, the design impact within the whole lifecycle belongs exclusively to companies' definition and depends on their environmental maturity level. Adding to that, the WEEE and RoHs legislation should tough be taken into consideration, that means, the limitation and prohibition of some hazardous materials in electronic boards control.

9.4.1.2 MOL-Middle of Life

The MOL corresponds to the use phase, service and repair (Jun et al., 2007; Wuest and Wellsandt, 2016). Once installed, as showed in Figure 2, the equipment will occasionally undergo maintenance and also a series of complementary services, depending on the contractual agreements established between customers and providers during the BOL phase (section 4.1.1).

Some examples of services in this phase are (Kreye et al., 2015): corrective/preventative maintenance; quality insurance; security inspections and support; product upgrades; telephone support; emergency calls; spare parts supply; guaranteed response time; hardware and software upgrades; extended asset uptime; after office hour support; technical training; performance guarantee, performance monitoring, report and adjustments. Many other activities can be mentioned, yet need to be well conducted to prolong equipment's life and reach further environmental benign benefits.

Figure 2 shows the main aspects (in terms of contractor decisions in PO-PSS) taken into consideration when maintenance is performed. Noteworthy to emphasize that maintenance in RO-PSS and UO-PSS are included in the "price package" as market practice. To make the choice about which kind of maintenance contract will be selected, contractors usually have an equipment criticality scale. In these criteria not only the number of exams needed are accounted for (in terms of the impact of patients' line), but also the revenue obtained by each type of exam, to guarantee that the better-paid exams do not stop being executed. As explained by *Imaging Equipment Manager – Case #B*: "*All the equipment that is critical, which we categorize by the use and revenue per exam, MRI, tomography, hemodynamic, digital x-ray, this equipment we work with maintenance contracts with parts included.* […] *And less complex equipment, an x-ray, an ultrasound, we only contract the maintenance "workforce", because if there is some broken piece, we have more time to negotiate, or even to redirect patients to other equipment (trying to maintain the schedule) without causing much impact on the patient in line."*

Maintenance Contracts: Result-Oriented (RO) vs. Product-oriented (PO) PSS

In RO-PSS, the level of the service agreement is high, complex and intensively discussed in initial contractual agreements, as described by the *Laboratory Physician /Manager – Case #C*: "*Machines that are not ours, from lending contracts, always include preventive and corrective maintenance.* […] *with pre-established service levels.* […]. On the other hand, in PO-PSS, since there is a huge variation in contractual agreements, the manufacturer-contractor relationship depends basically on the contractor business strategy.

Another step in the maintenance of PO-PSS is the decision between using the manufacturer's service or a "cheaper service" from the "parallel market" (second-hand equipment). Figure 2 highlights the decision process of maintenance contracts (contractor's decision perspective), with estimated percentages suggested by respondents. Most low complexity and low revenue-producer PO-PSS equipment do not have maintenance contracts and this service is performed by others than the original manufacturer.

The cannibalization of equipment performed by the second-hand "dealers" is also a regular discussion within the market professionals, according to a *CEO – Physician - Case #I*: "*he (the technician) is doing his work isolated (by himself), without having a relationship with GE. Currently, I just need to buy the component. And he ... gets the piece because he […] has some contacts. And it comes cheaper also […] in fact, he has equipment just like mine that is used only for dismantling. When some part in my breaks, he brings it and exchanges*."

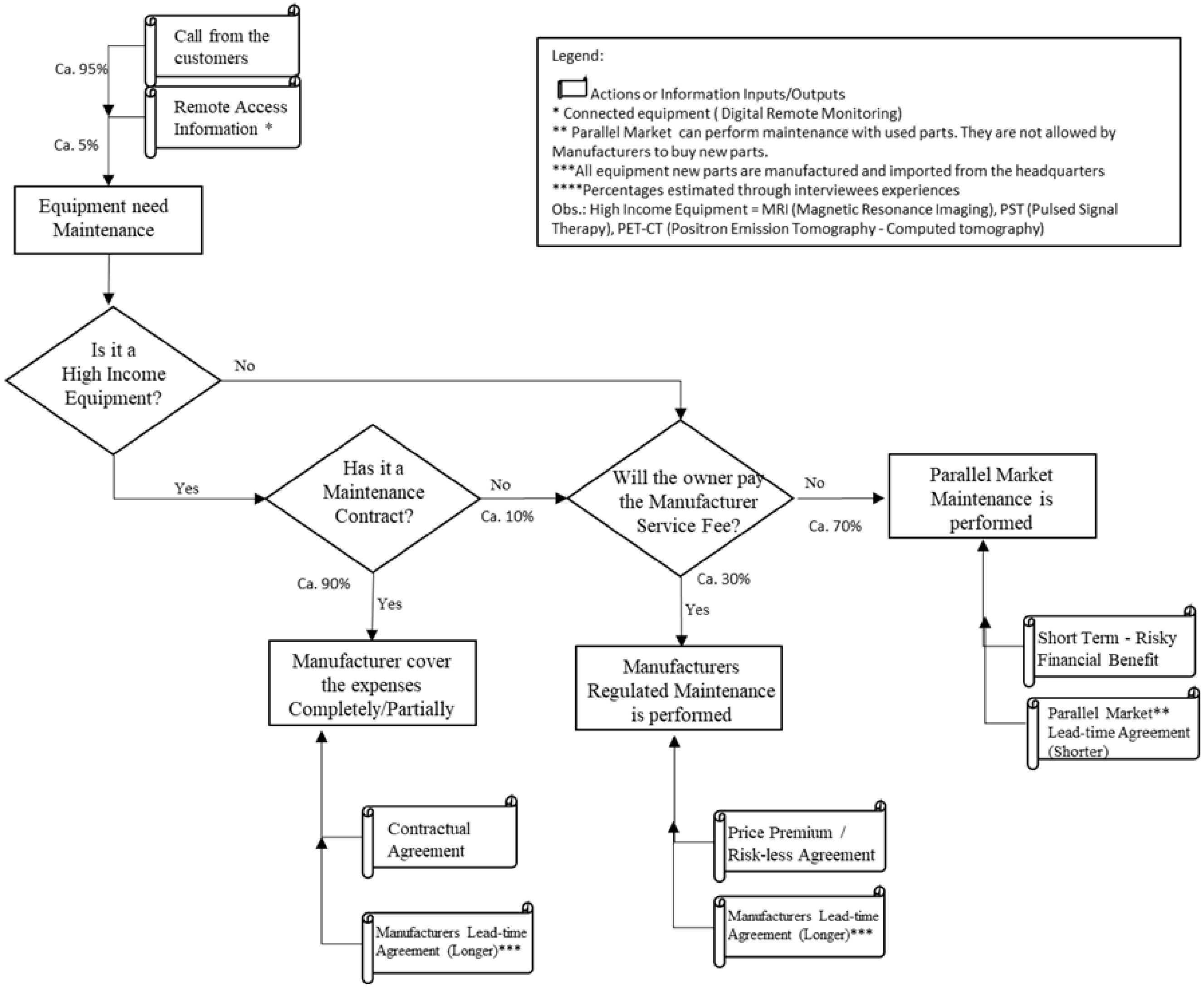

Figure 2: Healthcare Equipment – Maintenance of PO-PSS health equipment in the MOL Process (in terms of contractor decisions in PO-PSS).

Keeping internal maintenance teams, in parallel with external contracts (with or without parts included) is a practice in large health organizations conglomerates. Yet, new parts are still a bottleneck, according to the *Imaging Equipment Manager – Case #C,* that mentioned, *"*[…] *you can have a strong (maintenance) team, no matter how strong it is, you'll need to pick up that supplier's part and the parts are the most expensive components of maintenance, it's not the workforce."* The actual business configuration confirms Wise and Baumgartner (1999) theory, "Delivering a great product is not enough to get the loyalty of a customer. You must offer a combination of services that minimizes the overall costs."

PSS Outcomes - Performance, Consumption, Availability and Evaluation measures

According to the *Imaging Equipment Manager – Case #C*, performance evaluation represent a complementary service, which requires extra payment, is sold as a consultancy service, he added that, *"we have tried to talk to them (manufacturers) about performance management sometimes, but these solutions they want to sell and they charge well.*[…]. *In fact, this information they use to negotiate with us, it is strategic to their business ..."* Despite this business arrangement, consumption and energy performance is a subject in which not much attention is given, not by the manufacturer and neither by the contractor. According to *Customer Service Engineer Manager – Case #O "*[…] *at least in all the training I did no one has ever mentioned consumption aspects.* […] *this is not even quoted. We only focus on technical discussions, installation issues: power needed, configuration, if the place will be suitable for installation, and so on… but sustainability, energy-saving or material consumption is not even quoted."*

Availability is one key issue when it comes to performance evaluation, for both the customers and manufacturers (PSS providers), and even more critically for the case of RO-PSS, according to *Customer Service Engineer Manager - Case #O, "*[…] *we are mostly charged for equipment availability. In fact, each engineer allocated in the customer is responsible for a group of machines and we will be charged for them at the end of the year.* […] *Machine shutdown availability is heavily targeted, also because of contractual issues,* […] *if we do not reach our target, we may suffer contractual penalties and payment discounts."* Adding to this issue, and regarding service evaluation, according to *Contracts Manager - Case #B,* "*in all contracts, it is mandatory to answer a monthly evaluation questionnaire. The evaluation items involve questions about equipment, processes alignment, provision of scientific services, of maintenance service,*

service readiness and so on. Those rules are used for payment. So, below a "seven" note, I start to discount payment. We need parameters. And all this is formalized so there's no such thing as "Oh I did not know."

9.4.1.3 EOL-End of Life

EOL in PSS can be defined as post-use alternatives to the product, or its components and parts. Handling of EOL products components may include one or more of the options: reuse, remanufacture, recycling, incineration, landfill, and special handling (CONG; ZHAO; SUTHERLAND, 2017). Among these EOL options, reusing and remanufacturing offer better opportunities to reclaim the money, energy, and material investments (SUTHERLAND; GUNTER; WEINMANN, 2002). However, product life cycle performance is largely influenced by the decisions made at the early phase of product/service development (FADEYI; MONPLAISIR; AGUWA, 2017), such as modular architecture to ease product disassembly, to improve product serviceability and cleaning processes. Adding to that, consumer decisions during the use phase such as repair, pass on or throw away product due to post-warranty maintenance costs and product functionality directly affect product life span and as a consequence the rate of waste generation (SHOKOHYAR; MANSOUR; KARIMI, 2014).

Figure 3 shows the main aspects of the equipment end of life process according to health care market practices. Once the equipment's end of service is decreed, and it belongs to the customer, the latter should decide if he wants to change for upgraded equipment of the same brand, or change the equipment's brand. Keeping the same brand, the manufacturer himself sends the old equipment to a waste management company that will perform environmentally adequate disposal. In the case of brand change, the customer himself has to manage the equipment end of life, either by negotiating with the parallel market (second-hand equipment dealers), selling it to other clinics/hospitals, or sending it to a waste management company (and paying for that). In the case of RO-PSS, or UO-PSS, that the manufacturer keeps the ownership of the equipment, usually, they are evaluated in the manufacturer's repair shop. In the case the equipment can suffer an upgrade or can have the old "used/broken" parts replaced, they are repaired and reused in another contract. On the contrary, selected parts are sent back to the headquarter to further component analysis and recovery of worthy materials from special electronic boards or to occasional remanufacture. In that case, a waste management company performs the scrapping of the remaining equipment's structure and components.

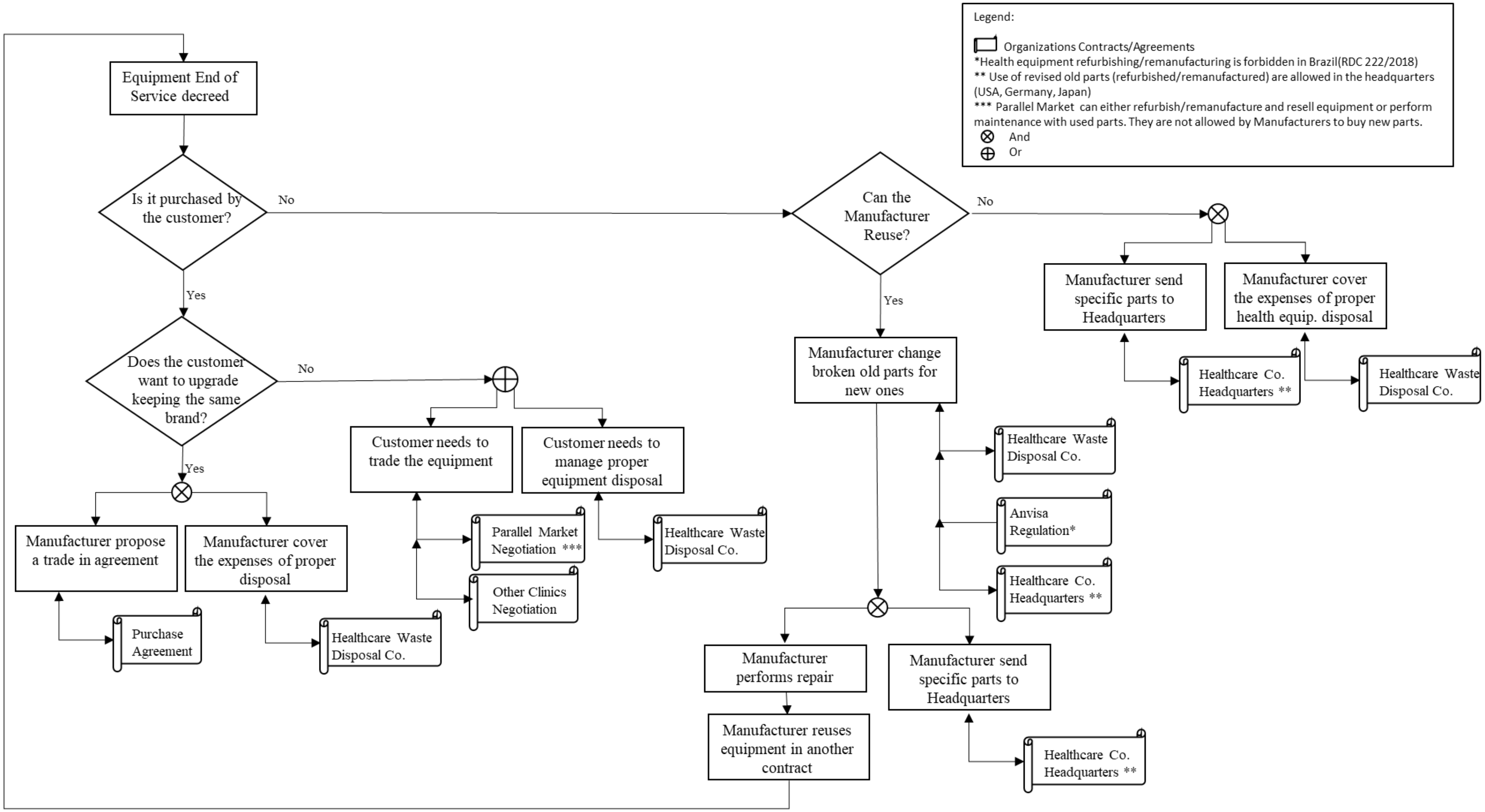

Figure 3: Healthcare Equipment – EOL Process (in terms of contracts differentiation).

9.4.2 Mapping stakeholders in the ecosystem

The main groups of stakeholders that stood out in the interviews were identified and analysed. As the stakeholders in the ecosystem changes along with the lifecycle phase, they are analysed accordingly. Table 3 shows the main types of stakeholders identified.

Table 3: Main stakeholders in health business ecosystem.

Main Stakeholders	**Stakeholders' Examples**
Contractor *(PSS Customer)*	Public or private hospitals, clinics, laboratories, and all its internal stakeholders.
Manufacturer *(PSS Provider)*	Large business players of the health ecosystem, equipment and service providers, with all its internal stakeholders.
Sub-contracted *1 to n* *(Supply Chain Organizations)*	Material suppliers, Technology developers, Logistic support, Communication platforms companies, Digital Enablers, Consulting Companies, etc.
Products Councils *(Regulatory Entities)*	ABIMO (Brazilian Association of National Health Product Equipment); ABIMED (Association of Importer Manufacturers); CBDL (Brazilian Chamber of Laboratory Diagnostics); ABRAMED (Brazilian Association of Medical Images); CBR (Brazilian College of Radiology), etc.
Professional Associations *(Regulatory Entities)*	CREA (Regional Council of Engineering and Agronomy), CONFEA (Federal Council of Engineering and Agronomy), FIESP (Industry Federation of the State of São Paulo), etc.
Regulatory Agencies *(Regulatory Entities)*	Anvisa (National Health Surveillance Agency), Inmetro (National Institute of Metrology, Quality and Technology), Conama (National Council for the Environment), Cetesb (Environmental Company of the State of São Paulo), ANS(National Agency of Supplementary Health) (they are inspection and intervention organs representing federal, state and municipal power to check specific aspects of each relationship such as insurance companies, health equipment import, health products quality, municipal waste disposal, etc.)
Federal Policies *(Regulatory Entities)*	Represent the regulation developed by the Ministries of Health, Environment, Finance, among others.
2nd Hand Mkt *(Second Hand Market)*	Organizations that negotiate used equipment, buying used ones, sometimes repairing them and reselling on the second-hand market at lower prices (irregular market); Those organizations occasionally have Anvisa's allowance (certification) to provide maintenance services, however, manufacturers do not allow them to buy original spare parts.
Waste Disposal M. *(Waste Disposal from Manufacturer)*	Organizations contracted by the manufacturers to perform the EOL procedures of used/obsolete equipment from their contractors.
Sub-contracted *wm1 to wm nz* *(wm - Waste from Manufacturer)*	Plastic recycling companies (depending on the type of plastic, many different sub-contracted), Co-processing in the cement factory (non-recyclable plastics); Recovery of precious metals companies, Metals Recycling (organizations related to the Waste disposal M).
Waste Disposal C. *(Waste Disposal from Contractor)*	Organizations contracted by the contractor to properly dispose of their health waste and occasionally broken parts of their medical equipment, or obsolete equipment not intended by the manufacturer.
Sub-contracted *wc1 to wc nz* *(wc - Waste from Contractor)*	Plastic recycling companies (depending on the type of plastic, many different sub-contracted), Co-processing in the cement factory (non-recyclable plastics); Recovery of precious metals companies, Metals Recycling (organizations related to the Waste disposal C).
Digital Enablers C. *(Contractor Digital Enabler)*	Digital solutions organizations (usually start-ups, or SMEs) contracted by the PSS customer to implement digital controlling of equipment parameters and general performance through sensors installation, use of IoT or general ICT solutions.
Medical Insurance *(Health Agencies)*	Operators, private companies or public entity (Unified Health System - SUS) that provide the service of medical and hospital assistance. Bridge the business relationship between patients and health entities, allowing patients to use the facilities of healthcare institutions upon payment of a service fee (in public entities in Brazil, it corresponds to the tax fee).

Patients *(End Users)*	Those who need medical and clinical care, either because they are sick or suspect that they have an illness

Figure 4 summarizes the main groups of stakeholders involved in the BOL, MOL and EOL phases of health equipment. Note that the thickness of the lines represents the intensity of the relationships between the stakeholders.

In BOL phase, the manufacturer-contractor connection is the most expressive relationship, aligned with the compliance prerequisites from the federal policies and regulatory agencies. Further intermediary relationships can be observed between product councils, professional associations, and diversity of sub-contracted organizations. The second-hand market is also represented (although usually irregular), contractors may use those companies as a “less expensive” option to acquire equipment, however, this parallel market is more common in PO-PSS equipment. Still, those companies are connected to regulatory entities, because most of their workforce is legally authorized (or have formal preparation) to deal with health equipment services.

In MOL phase, the network is especially characterized by the presence of the end-user (the patients) and the health agencies that make the business intermediation between the hospitals and clinics and the patients. Furthermore, the companies belonging to the parallel market act differently in this phase. They offer the service of maintenance with or without equipment parts. They are specialized technicians, usually owning their own business, after a period of experience in the original manufacturer company, but since they have market connections/acquaintances, they manage old pieces from disposed of equipment, to be refurbished or reused, for instance. Nurturing the CE technical cycles processes.

This activity is not regulated in Brazil, but due to insufficient inspection from regulatory entities, it is frequently performed. Noteworthy that besides the regulatory entities such as federal ministries, regulatory agencies, professional associations and products councils, the manufacturer (PSS provider), the contractor (PSS customer), and the members of the supply chain and the second hand market organizations which are also present in the network since the BOL phase, the role of the waste management companies come into scene. The latter is contracted by manufacturers and by contractors, with the goal of dealing with the waste generated during the use of the equipment, including maintenance activities. Usually, the main waste disposal management company sends specific parts to other partner companies specialized in different sectors to perform either recycling or co-processing.

Another important role identified is a digital enabler, working independently for the contractor. The digital enabler is gaining importance, due to the necessity of internal solutions mainly related to automating controlling aspects that sometimes manufacturers are not able to provide or provide in an “unfriendly” technological platform. Basically, with the use of ICT, those organizations gather the main monitoring information into an online system to make all responsible aware of the equipment status “at the moment”, besides providing some automated system responses. They are usually startups, or SMEs with expertise in digitalization, IoT and technological devices/protocols.

In EOL phase, despite similar with MOL phase, the waste management companies contracted by the manufacturers and the contractors are the most relevant in this life cycle phase, as well as the organizations belonging to the parallel market, creating a business from obsolete equipment. Noteworthy the importance of subcontracted (partner companies) by waste management companies, such as plastic recycling companies, cement industry, metal recovery companies, among others. The level of importance of regulatory entities are larger, due to controlling and inspection activities regarding legally adequate materials disposal.

Figure 5 synthesizes the three life cycle stages within the main groups of stakeholders and the types of relationship between them. In red: goods, service, money and information exchange. In black: information, documentation and service exchange only. Dashed lines represent intermittent/alternative relationship, while straight-line represent a continuous relationship. The dashed line with stars represent the touchpoints between manufacturer-customer in the case o PO and UO-PSS. The BOL phase is characterized -for the lack of waste management companies, while MOL is characterized by the high volume and intensity of interactions between stakeholders, including insurance agencies and the end-users (patients). EOL emphasizes the role of the parallel market and the waste management companies once the equipment’s end of service is decreed.

Regarding the three types of PSS, and the service provision between contractor and manufacturer, a pictorial example of interactions is showed in the bottom of Figure 5. While RO-PSS requires continuous interaction, PO-PSS requires intermittent interaction, with specific touchpoints throughout the PSS life cycle. UO-PSS (renting contracts) are concentrated in the MOL phase of the PSS and has usually touchpoints in the beginning and end of the rental contract, with occasional maintenance events during the usage period.

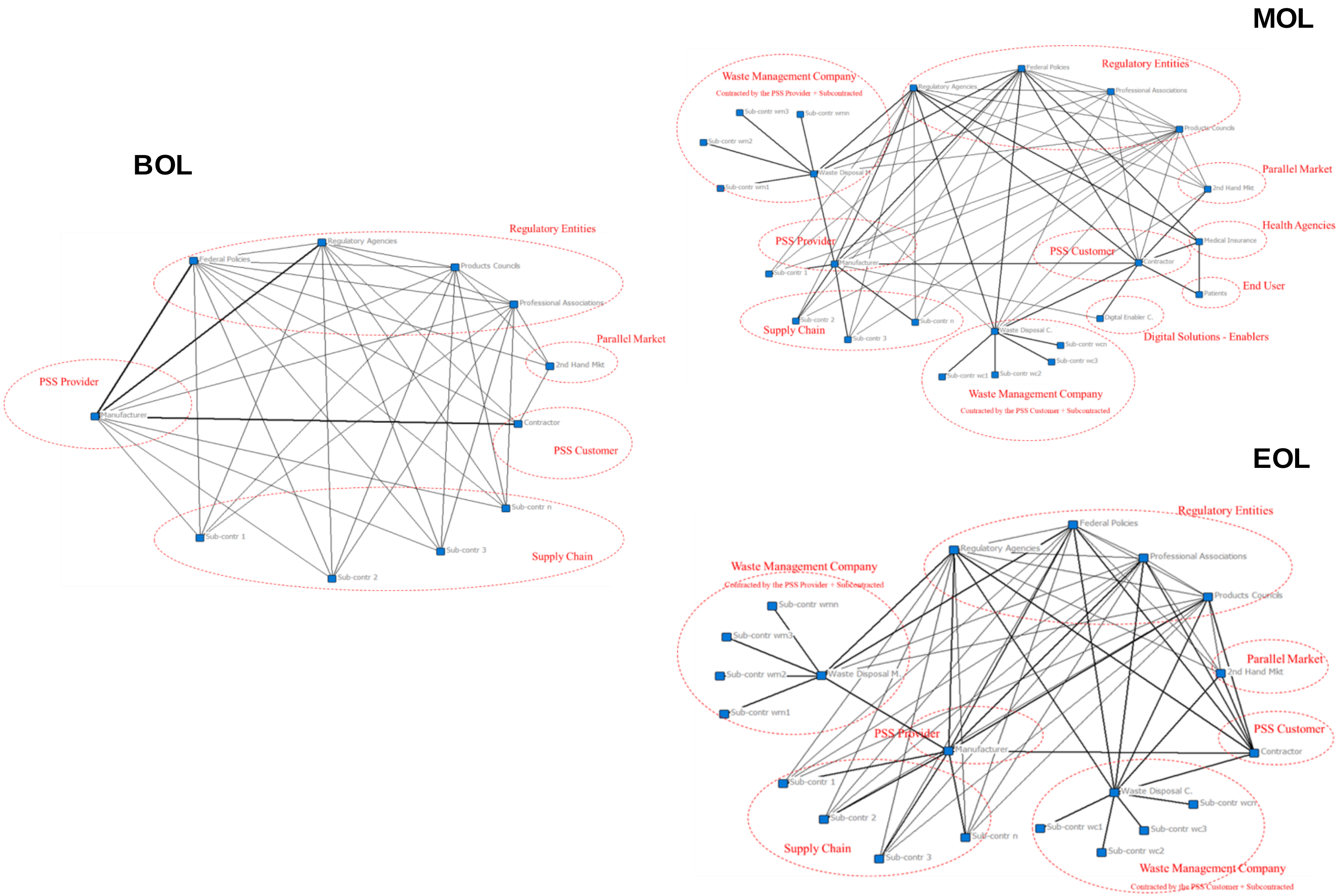

Figure 4 - Main groups of stakeholders involved in the BOL, MOL and EOL phases of a health equipment.

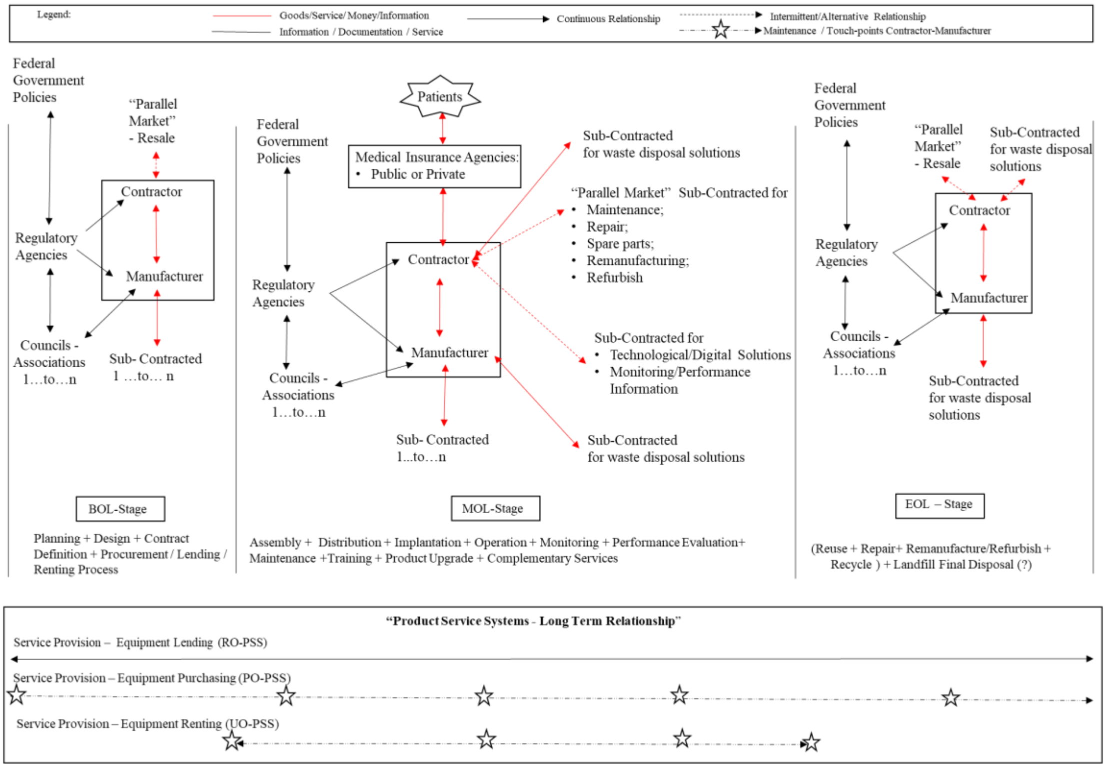

Figure 5 - Overview of BOL, MOL and EOL stages with main stakeholders' groups for health equipment (PO, RO, and UO-PSS).

Figure 6 shows a comparison of the two extreme business modalities usually performed for laboratory equipment (RO-PSS) and imaging equipment (PO-PSS). UO-PSS can be performed by either the equipment, but its contractual aspects are mostly aligned with RO-PSS. The types of laboratory equipment and imaging equipment are listed on the right side of the figure. Main contractual aspects differentiation is characterized in the central description boxes for lending and purchasing contracts. Those examples were selected because they are positioned in the extremes of PSS modalities from each other. While laboratory equipment is intensive in consumables, with low income per exam, and less time consuming per result, with the less expensive workforce (technicians) it is a business modality that is maintained due to the number of exams that need to be daily performed. Imaging equipment is less intensive in consumables, have higher income per exam and are extremely depending on the physician workforce to perform the exam analysis (expensive workforce), for that reason, more time consuming, since automation has not reached satisfactory results in this area. Regarding EOL, the owner is always the one responsible for the final disposal and proper environmental procedures. Since the original manufacturer usually keeps the ownership in laboratory equipment, the latter is responsible for the EOL procedures (usually hiring specialized waste management companies). In PO-PSS, the contractor is responsible for the EOL procedures, however, due to financial reasons can opt to re-sell the equipment into the "second-hand market", making more profit, instead of paying for a proper "officially regulated" disposal in waste management companies, or returning it to the manufacturer in exchange for a poor counterpart.

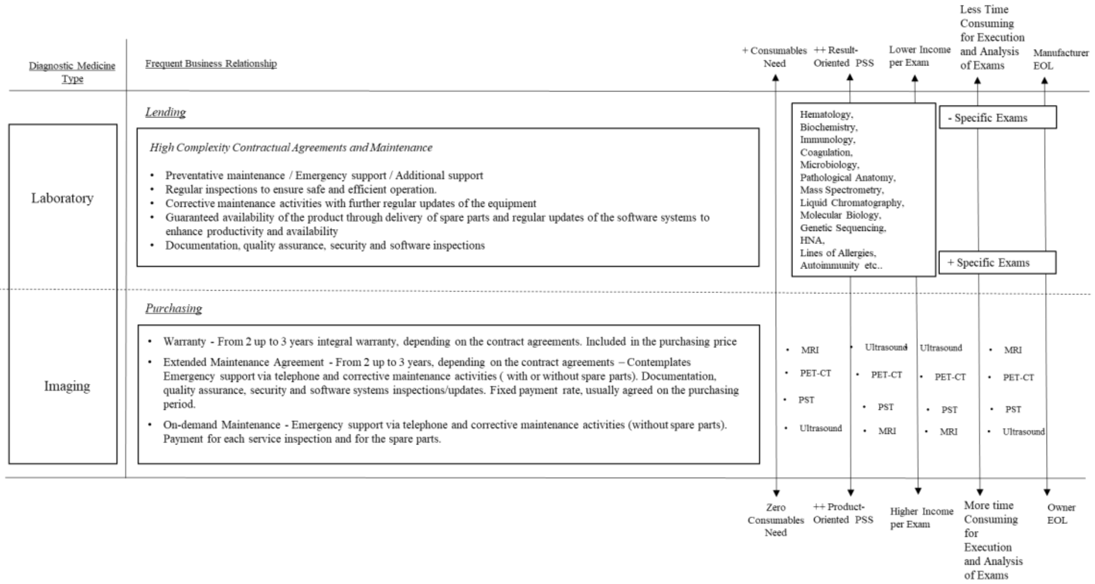

Figure 6: Comparison between laboratory equipment (RO-PSS) and imaging equipment (PO-PSS) highlights from the cases.

9.4.3 Overview of Healthcare BE

For many decades there was much research related to types of materials and technological solutions aimed at patient's health recovery. On the other hand, little attention was given to integrated assessment of value delivered, management tools to track invested financial resources in each health recovery case, assessment of equipment performance, integrated management platforms aligning resources utilization, incomes, equipment monitoring, level of services, patients flow, quality of services, quality of health recoveries and so on.

Unlike financial institutions or manufacturing industry itself in which management gears need to move with interdependence, and much automation has been developed, health experts (nurses, doctors, physician and so on) with limited academic training in management skills and health industry focused in products development have always led healthcare sector. In current times, however, it is observed a movement in health institutions towards more managerial skills to cope with sustainability (financial, environmental and social) challenges. According to the *Service Director – Case #O* "[…] *we're still at the very low patient interaction level. A great challenge is how we change our level of interaction with the direct patient so that the patient begins to have a perception of the value of the technologies that are being used and that the* *dream that he may one day differentiate technology and choose according to information come true.”.*

Health Insurance Companies and Social Issues

Health insurance companies (public or private) in Brazil face increasing financial difficulties, either for the aging of the population, that demand more healthcare services or for the broad inefficient public health service, or for the sake of profitability of private health insurance agencies. The fact is, the diagnostic exams are underpaid independently of the level of excellence of their services. According to *CEO – Physician – Case #A: “The guys (medical insurance companies) want to massacre you. This is a big problem in Brazil. Chile, for example, depending on the quality of your equipment, you raise your class in the value table. Not here. Here if you have a $ 50,000 or a million-dollar handset, the amount health insurance will pay you for the exam is the same. You start scraping the technology park.* […]. *So, if you take an ultrasound in Brazil, most of them are over 10 years old (they should have a maximum of 5). There are some who are 20 years old.* […] *Also, it is not our reality, in our service they are all last generation, all new. But we have to do this because we are a reference in the market. But it is no longer a country reality.”*

The reality of the health is the fee-for-service business model, in which the person pays for each service that is offered to him/her. And the counterpart to the health hospitals and clinics happens the same way, they make revenue over the number of exams, and procedures offered to the patients. Regarding private health insurance companies, that promote the intermediation between hospitals and clinics with the patients, have an insurance annual readjustments level within a basis of 12%, 13%. Noteworthy that it is officially announced that the main reason for such an increase is the costs of the “hospitals/clinics”, yet, according to *CEO – Physician – Case #I “*[…] *we cannot negotiate the table of values per exam. The companies are closed.* […] *I fight to get the inflation adjustment at least. There was no increase. But they use this as an alibi to justify their cost.”* Moreover, the government and regulatory agencies should work in that direction to improve quality and to promote growth, but as reinforced by the *CEO – Physician – Case #A, “it does not work that way. Why? Because ANS is in the hands of health insurance providers.* […] *And there is no interest in changing anything.”*

Regulatory Agencies in the Ecosystem Perspective

ANS is a regulatory agency linked to the Ministry of Health responsible to regulate operators (including the relationship with providers and consumers) of the health insurance sector in Brazil (ANS, 2019). It is responsible to check organizations compliance and the rights of the insured. However, what has been observed is that despite the high levels of readjust charged on the insured, the service level is decreasing precisely because the adjusted value is not even partially passed on to healthcare services (hospitals and clinics).

Another regulatory are directly influencing the healthcare ecosystem is the National Health Surveillance Agency (Anvisa), a national regulatory agency also linked to the Ministry of Health. The agency exercises sanitary control of all products and services (national or imported) subject to sanitary surveillance, such as medical products, blood derivatives, and health services. This agency is responsible for the monitoring and control of the Resolution of the School Board of Directors (RDC) n. 222/2018 which deals with hospital waste management, in fact, waste of health service (including end of life of materials and equipment).

The *Clinical Engineering Manager - Case #C* highlighted the role of Anvisa discussing that *"Anvisa has a fundamental job,* […] *it is logical that it has its difficulties as any regulatory body,* […] *thinking about the country, Anvisa has set the minimum conditions, it has to meet that minimum, there's no other way."*

In this sense, a special situation occurring in Brazil was mentioned by the *Technology and Health Products General-Manager - Case #R*: *"ultrasound equipment, for example, goes into the common trash despite having a lot of lead, mercury, cadmium, heavy metals in the electronic boards, internally.* [...] *in the case of Europe, there is a RoHS (Restriction of Certain Hazardous Substances), a directive limiting the amount of these heavy metals. Last year an initiative from the Ministry of Environment, with Anvisa and other organizations complemented the law of solid waste (Law nº 12.305/10), with a Brazilian RoHS directive.* […] *Meaning that for the equipment to be commercialized here in Brazil, it has to comply with this directive, limiting these heavy metals in their components. It has not been concluded yet, but is in the process of being concluded"*. In Europe, WEEE or RoHs regulation came into force since 2003, in Brazil, in 2019, due to the complexity of stakeholders' influence and numerous competitive interests, the law is still under approval.

Public Policy within Research and Development Processes

Regarding hospitals and manufacturers research partnerships, in Brazil, the focus is on improving manufacturer's product, and use government and institutional tax incentives, converting the taxes directly into research funding through the Law nº 11.196/05 (known as Law of Good). According to *Innovation Director- case #C:" We can perform a large research project within the hospital, with cost, to be financed by GE. But GE would have to spend this money in taxes anyway. So, it becomes a benefit of the state, a public thing, and those large manufacturers can seize the opportunity to have their "name" linked to research and development."*

On the other hand, large manufacturing companies (usually multinational ones) are intended to invest financial amounts in national research and development activities, aiming at taxes incentives, such as exemption or reduction of the Industrialized Products Tax (IPI) for innovation in computer goods and automation (Law of Informatics, nº 13.023/14). However, often, due to internal difficulties in innovation processes, those companies transfer it to third parties, smaller companies, in which the core commitment is the development of digital solutions. *According to the Executive Director- case # T: "Large companies do not like the word development.* […]. *I understand that they usually take a lot of time and money to perform any kind of development, they move slower. That is the reason for resistance. Usually, we say that we have the solution ready, or almost ready, and, in fact, only then we begin the development. And perform well, actually, exceeding the expectation because we do it fast. It is another dynamic. That is a real difficulty in this environment."*

The configuration of the business development might influence positively in the partnership between large healthcare equipment manufacturing and small companies of digital development. However, peripheral innovations are usually favoured by those governmental incentives, since most of the development comes from the headquarters. *"These large companies eventually partner with, sometimes, immature research institutes that need to be registered in the Ministry of Science and Technology to receive the funding. Hence, manufacturers end up receiving this govern incentive, but in counterpart require the development of some very peripheral work. They maintain this ecosystem of many of these little useless projects, making many engineers work on things that are not really going to turn into something, which means with very little applicability." Executive Director- case #T.*

Digitalization and government influence

Currently, digitalization plays an important role during the MOL, however, in healthcare some aspects emerged, differently from the industrial manufacturing background (ANNARELLI; BATTISTELLA; NONINO, 2019). Digital remote monitoring of equipment information, for instance, was mostly discarded as a means to support a proactive manufacturer's intervention in PO-PSS contracts. In this sense, sector's particularities were emphasized by some interviewees, regarding the background and the motivation for high-tech digitalization implementation. According to the VMO-Manager – Case #C, "The investment in the area of Health was much greater for patient's direct assistance product than for the provision of services. So, we do not have great tools for connectivity, for data integration. When you look at information, the investments were not the same size as investments for medical products."

Another aspect regarding the limitation for the digitalization level in this area is the balance between investment and the proportionality of income received due to the investment level. In other words, in Brazil, the health market for diagnostics has a settled, price "per exam" based on the SUS (Unified Health System) definition. And private health insurance companies define exams prices based on the lowest price available in the market. As stressed by the Innovation Physician – case #C "Companies in Brazil, health funders, health care providers, usually associated with the individual having a sub-operator associated with a company, want to reduce costs, reduce the level of complexity of health treatment in all instances".

These aspects bring important insights into the business ecosystem situation. One consequence of this health policy is the low interest for high modernization of health equipment, because independently of the quality of the exam, the revenue received per exam, will be exactly the same. In contrast to this policy are those institutions that value the strategy of differentiation, and also charge "price premium" private insurances, in exchange for the best quality equipment and services, which corresponds to a few percentages of the current health providers.

In fact, it can be assumed that the government plays a fundamental role in controlling health providers, even "indirectly", through SUS and ANS definitions (see table 3), which hinders some business negotiations in the sector. The Service Director – case #O, emphasizes also another aspect regarding health digitalization: "the transformation in the Health chain undergoes a reorganization of the data where you put the patient in the center of attention. Most of our systems are developed based on billing. You can not have a centralized view of the patient. The more mature clients are the more allied with the trends of the future".

Aiming to represent the relationships of the main government agencies with other stakeholders in the health business ecosystem, Figure 7 shows the main groups divided in three interaction levels: macro system level (federal government policies); mesosystem level (organizations network) and microsystem level (individual organizations) (GHISELLINI; CIALANI; ULGIATI, 2016).

The main aspects that constitute barriers to the further development of the sector hindering regulation to more sustainable equipment lifecycle activities towards new and improved business development are shown in the right side and the enablers are in the left side, within the corresponding system level. The whole ecosystem should be centred in the patients (end-user and the main reason for the healthcare business ecosystem existence), even though not all stakeholders seem to have it clearly stated. Figure 7 represents the synthesis of these main aspects discussed and coded within de 20 case studies. Once the main influences are punctuated and clarified, it may lead to new approaches towards improvements in the whole system.

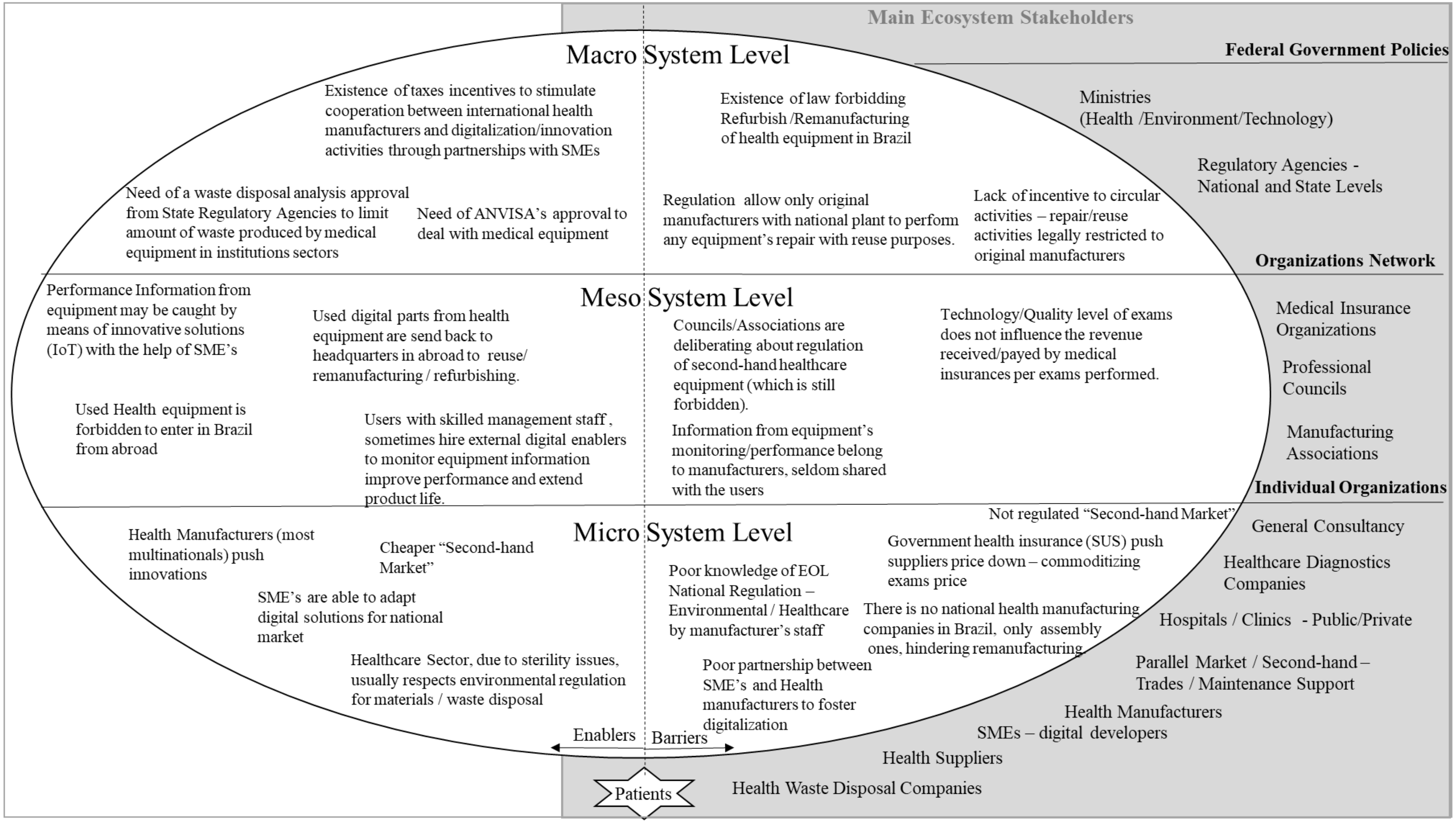

Figure 7: Interaction levels of Healthcare BE with the respective stakeholders' group distribution.

9.5 Conclusion

This paper contributes to the understanding of the Healthcare BE influence in motivating the development of PSSs business model. An in-depth empirical investigation was performed within twenty case studies in the Brazilian healthcare sector. Findings from the research suggest that the dynamic of the BEs encourage the development of specific PSS trajectories within the Brazilian environment. Namely, for RO-PSS and UO-PSS business contracts, the providers' business trajectory regarding the EOL procedures follow regulatory pathways. For PO-PSS, new business solutions emerge, challenging policies and regulation, by extending and intensifying products' life cycle both to save economic resources from PO-PSS customers and to take advantage of a market opportunity enabling numerous SMEs to deal with second-hand health equipment (influencing also in social issues regarding job creation). In both business trajectories, the sector is improving towards sustainability, nevertheless, different drivers stimulate activities development and policymakers are fairly far from orchestrating the BE through regulation. To clarify each group of stakeholder's roles, a framework is proposed based on the case studies and the literature analysis to represent the interaction between the actors of a PSS business Model and its Lifecycle stages within the Business Healthcare Ecosystem (figure 5). The main aspects of fostering and hindering business within the PSS BE is also synthesized in a three-stage system level (figure 7).

This paper provides strong implications for research theory and practice, and some important aspects of the findings must be emphasized. First, the natural pattern of regulation and policies development is that they usually come right after the business emerges within the business ecosystem. That is, regulatory measures are developed to organize the involved stakeholders once any new business activity is being performed. Which stresses the issue about the necessity of regulation to foster second-hand equipment business, collaborating with sustainability aspects (environmental, social and financial).

Second, according to our findings, the configuration of the health system is mostly guided by the need for survival of health insurance plans (either public or private), controlled by the government, which ends up transforming the revenue per exam in a commodity, whose price is determined by supply and demand. The consequence is that in the Brazilian healthcare business ecosystem, there is no differentiation in the rewarding between better quality exams (which theoretically are performed by new equipment, with better technology) and less quality exams (which are performed by the oldest equipment still allowed in the diagnosis market, limited to the availability of manufacturers spare parts and maintenance). This ends up by levelling down the industrial park of diagnostic equipment in Brazil. Another consequence is that, since the number of suppliers is high and gains in scale are especially practiced by large conglomerates of clinical diagnostics organizations, the entire health industry must reduce its costs and increase production to guarantee competition. Moreover, the charged prices, which are established and provided by the health insurance organizations, are defined by the lowest price practiced in the whole health market. This evidences that the government influence is unbalancing the BE.

Third, among the empirical findings, it is evidenced in the health market that in RO-PSS and UO-PSS contracts, environmentally more sustainable practices are led by necessity from the PSS providers, and occurs mostly in the EOL stage through the transformation of manufactured products into raw materials (by recycling and re-processing). In PO-PSS, a solution emerges from the business ecosystem configuration and is led by thousands of small and medium enterprises (SMEs) as an opportunity for both second hand “dealers” and PSS customers. In fact, while RO-PSS business is driven to avoid the reuse of parts, components, and even the completely used equipment, exactly these aspects drive PO-PSS towards new business opportunities (more aligned to sustainability practices through reusing, repairing and refurbishing).

In terms of managerial implications, our research shows that there are some regulations to economically foster the partnership between scientific research, large manufacturers and SMEs towards innovation and development, yet it must be better orchestrated to reach more significate results. Socially and economically, besides generating many parallel jobs and influencing in the attendance of many health patients, they are responsible to make feasible many businesses in the healthcare diagnostic sector. Therefore, partnerships and cooperation should be nurtured by managers to ensure more win-win situations, instead of disputing over who belongs the account. This research also has strong implications for public policy in creating and nurturing an environment that supports new business opportunities through further health PSS development. Besides, the findings reveal that in the Brazilian healthcare ecosystem, conflicts of interests are one of the greatest barriers to reach faster results. They influence in the regulation delay towards equipment life cycle extension, for instance, by prohibiting the sale of used equipment, unless fully reviewed by the main manufacturer, which ends up by making the trade costs unfeasible. In fact, there is an extra impulse in the BE for the creation of different business models or the identification of new business opportunities once economic barriers (financial attractiveness) impose innovative solutions.

Thus, future investigations are needed to work on the role of policymakers to regulate BE configuration fostering new business aligned with sustainability. The comparison within the reality of a developed country may also enrich the understanding of the health BE configuration. For future studies, the BE configuration of other industrial sectors can also be analysed, to broaden the comprehension of the relevant contextual specificities. There are some limitations to this study regarding generalization since the cases were performed in a specific sector, the Brazilian healthcare BE and for that reason, the research results need to be interpreted in light of this specific context. Additionally, it must be mentioned the researchers and the interviewees bias that might influence the results in qualitative approaches. However, this work brings real aspects from a complex sector that can give insights for both academy and managers.

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10 #P5: How are product-service systems helping the healthcare sector to face the challenge of circular economy?

Journal:	Resources, Conservation, and Recycling
Authors:	Aline Sacchi Homrich, Steve Evans; Marly Monteiro de Carvalho
Status:	Submitted in nov/2019 to the Resources, Conservation, and Recycling Journal

Abstract

Product Service System in Healthcare has a great potential to leverage sustainability; circular economy technical cycles are embedded especially if adding to the functionality deliver idea. Yet, there are great barriers to overcome in one of the most complex and regulated systems of the world. This work aims to contribute to this conjunction of ideas, by enlightening circularity possibilities in PSS business models developed in the healthcare sector towards sustainability. Besides, it investigates the role of digital technologies in this context. Semi-structured interviews within 16 companies and 50 interviewees were performed in Brazil and in the United Kingdom. The same profile was purposefully selected to compose the sample of the eight organizations in each country, namely: manufacturing/service companies, regulatory agencies/government, digitalization organizations and public-research hospitals. The results reveal the main aspects of each stage of a product service system lifecycle emphasizing circular economy technical cycles opportunities influenced by the business favourability to CE, digital technologies, stakeholders network and regulation to foster circularity. Finally, a framework shows the integration of circular economy technical cycles opportunities, PSS lifecycle and the stakeholders' network. This research contributes to broadening the understanding of the challenges regarding Circular Economy implementation towards sustainability in healthcare, proposing future pathways to overcome them.

Keywords: Healthcare; Product Service Systems, Circular Economy, Digital Technologies Lifecycle Thinking.

10.1 Introduction

The Healthcare sector is worldwide characterized by a significant number of particularities and for its high complexity environment (PwC, 2013). Adding to this scenario, sustainability is a worldwide issue that has a special weight in healthcare due to the hard consequences that lack of environmental care with healthcare waste may cause (KANE; BAKKER; BALKENENDE, 2018). The UN stresses that over half the world's population might become ill due to irregular healthcare waste management (GEORGESCU, 2011).

In this sense, the operationalization of sustainability through circular economy principles and technical cycles has been faced as an integrated alternative to balance "economic prosperity, environmental quality, and social equity" (ELKINGTON, 1997; MACARTHUR, 2013). According to Kane et al. (2018), it is, however, difficult to introduce circularity strategies in the healthcare field, first because of sterility aspects, second because of existing regulations on product safety. Furthermore, there is also a gap in the research on the existing "circular economy-focused literature in the medical sector" (KANE; BAKKER; BALKENENDE, 2018). To develop sustainable manufacturing, the creation of "manufactured products that use processes that are non-polluting, conserve energy and natural resources, and are economically sound and safe for employees, communities, and consumers" is mandatory (KHORRAM-NIAKI; NONINO, 2018). For this reason, healthcare is often mentioned as an area in which Product Service Systems (PSS) possess great potential (MITTERMEYER et al., 2011), because of the need of complete solutions, including physical assets and continuous operational services support to guarantee functionality to the customers' need (MONT, 2002); yet studies on this topic are still very scant (XING; RAPACCINI; VISINTIN, 2017). Adding to it, PSS has been currently seen as a business model that may enable the transition from a linear to a circular economy (KJAER; PIGOSSO, 2018), by optimizing the performance of a system through supporting users and other stakeholders in the "post-production life cycle stages" (KJAER et al., 2016).

In this context, this work aims to contribute to this conjunction of ideas, by enlightening circularity possibilities in PSS business models developed in the healthcare sector towards sustainability. We intend to bring empirical evidences of the manners in which the health-care sector is facing the challenges of CE, through the life cycle thinking lenses within an overview of the stages of a PSS implementation. Thus, the main research question leading this paper is:

How are product-service systems helping the health-care sector to face the challenge of circular economy?

Note that the multiple sectors affecting the health sector have a variety of stakeholder and interest groups, different cultures, values, and vocabularies and also usually lack experience in working together, which can also likely hinder partnership and collaboration (DELOITTE, 2019). Particularly, digital technologies (IoT, Big Data, analytics, cloud computing) have played an enabler role for PSS and circular economy connector (BRESSANELLI et al., 2018). They collaborate by remotely monitoring PSS performance, which directly influences an extension of the product life cycle. Moreover, they help with the equipment tracking control, making take back, end of life and closing loops processes more feasible (ARDOLINO et al., 2018). This leads to a second research question:

What is the role of different stakeholders in PSS networks and of the digital technologies in this context?

We perform the investigation through an exploratory research, presenting the main findings of 16 case studies within the healthcare sector, eight carried out in Brazil and eight in the UK. The same companies' profile in both countries was selected to perform a cross-country and cross-cases analysis. Findings from the research suggest that the dynamic of the stakeholders' network and specific CE policies encourage the development of different CE trajectories, according to the kind of PSS developed.

This paper comprises six sections. Section 2 offers an overview of the theoretical background. Section 3 describes the methodological approach of this research, while Sections 4 and 5 present and discuss the findings, respectively. Finally, Section 6 outlines the conclusions of this study.

10.2 Literature Background

10.2.1 PSS in Healthcare

Despite the several definitions of Product service system (PSS) for the purpose of this research, we adopted PSS as "a business model focused toward the provision of a marketable set of products and services, designed to be economically, socially and environmentally sustainable, with the final aim of fulfilling customer's needs." (ANNARELLI; BATTISTELLA; NONINO, 2016). That is, PSS can be a possible answer towards sustainability concerns since it allows companies to systematically and simultaneously address all the three dimensions of sustainability (economic, social and environmental)(ANNARELLI; BATTISTELLA; NONINO, 2019).

PSS seeks to improve the use phase (Amaya et al., 2014; Wang et al., 2011) through services, such as extension of products lifecycle through upgradability and complimentary services, improved availability of the product (through intensive maintenance processes) or through multiple users of the same product (GRÖNROOS, 2011).

Besides, PSS is frequently classified into three types (Beuren et al., 2013; Wang et al., 2011;Tukker, 2004, Neely, 2009): 1) product-oriented (PO), e.g. maintenance services or consultancy (after sales); 2) use-oriented (UO) e.g. bike-sharing or equipment renting; and 3) result-oriented(RO) e.g. “pay-per-use”, energy management services, healthcare laboratory equipment leasing. In any of the PSS categories, the provider extends the stewardship to cover more life cycle stages elements than usual sale, such as the use stage and end-of-life (BAINES et al., 2007). PSS evolution would follow this gradation scale, from the closest to usual product-dependent business (PO) to the most service and performance-dependent business (RO). In this sense, moving profitability away from the physical goods and towards the results delivered, stimulate the provider to adopt more benign environmental offers, ideally through dematerialization.

However, to achieve sustainability through PSS, numerous barriers can be identified, such as: need of changes in enterprise organisation and collaborators’ mind-set, ownerless consumption education to customers, close collaborative relationship with partners, collaborative product-service development, and further, Wang et al. (2011).

In fact, the literature suggests that by migrating from traditional product-focused business models to usage/result-focused ones, the potential for the circular economy increases. According to Kjaer and Pigosso (2018), the first step to move a PSS to a more sustainable business (regarding a relative resource reduction) is to improve the CE strategies throughout the PSS life-cycle. That is, make use of PSS enablers towards resource reduction, such as operational efficiency (support, maintenance), product longevity (maintenance, take-back, EoL management), intensified product usage (sharing), product system substitutions (sharing, EoL management and optimized results).

Although the healthcare sector is suggested to be a prominent field for developing integrated products and services (MONT, 2002), the academic literature on the subject is still scarce (XING; RAPACCINI; VISINTIN, 2017). The servitization challenge is however faced, regardless of the sector, towards a competitive differentiation within the market (VANDERMERWE; RADA, 1988). In this sense, owing to an explosion of costs in healthcare, due to an ageing population, the advent of new technologies and other issues, the pressure to reduce cost can be considered to be significantly higher than in other areas (Mittermeyer et al., 2011).

Still, according to Mittermeyer et al. (2011), within the stakeholders’ network, governmental regulatory authorities play a fundamental role “by setting the standards, requirements and restrictions", clearly influencing the market and its players in the health care sector. However, regulations are defined not only by the government, but also by the industry since the risks of drugs and medical device development need to be mitigated. Also, the healthcare industry involves multiple stakeholders that regularly have conflicting interests (Yip et al., 2015). In this scenario, three main layers of actors can therefore be identified: 1) framework-defining, e.g. regulatory authorities, governmental institutions and private health insurance companies; 2) technology-providing, e.g. companies providing products, services and combinations thereof to different users (specialised physicians); 3) end users (patients). Adding to it, knowledge broadening, faster diagnosis as well as patient-specific treatments, make the whole network of actors gain complexity. This makes "integration" a multi-dimensional challenge. (Mittermeyer et al., 2011).

10.2.2 Circular Economy Technical Cycles and Sustainability Related-Outcomes

According to Geissdoerfer et al. (2017, p. 759) "The circular economy may be defined as "a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops . This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling." In other words, CE aims to eliminate 'waste', either by product life extension or by 'looping' the product or its constituent materials back into the system to be reused. (KANE; BAKKER; BALKENENDE, 2018). Even though CE is not a final goal in itself, it is a part of an "ongoing process to achieve greater resource efficiency and effectiveness" (LÜDEKE-FREUND; GOLD; BOCKEN, 2019), and thus the sustainability related-outcomes.

However, it is difficult to introduce circularity strategies in the healthcare sector because of the existing regulations on product safety, and sterility aspects (KANE; BAKKER; BALKENENDE, 2018).

Circular Economy Technical cycles comprise: maintenance, reuse/redistribute, refurbish/remanufacturing and recycle (THE ELLEN MACARTHUR FOUNDATION, 2012). The addition of services, such as maintenance, upgrading, and remanufacturing, lengthens product life and therefore reduces product turnover (MONT, 2004), hence reducing the global ecological impact of product use. (DONI; CORVINO; BIANCHI MARTINI, 2019)

Note, however, the "rebound effect" that occurs when the actual resource reduction from an improvement is less than that expected because of behavioural or systemic responses (KJAER;

PIGOSSO, 2018); according to the authors, an example is when a more fuel-efficient car stimulates users to drive more.

However, according to Diaz (2017), in developing countries, such as Brazil, low CE activities are detected, mainly because of the "lack of political will, lack of national waste management policies, rules and regulations, insufficient funds dedicated to CE, and the absence of expertise and education at all levels." This situation causes the emergence of informal recovery, recycling and reuse markets, reaching circa 10% to 15% of total municipal and commercial wastes generated in developing countries (REIKE; VERMEULEN; WITJES, 2018)

10.2.3 Lifecycle and Digitalization

Digital technologies are considered critical enablers of the transition to CE at each life cycle stage (LEWANDOWSKI, 2016; BRESSANELLI *et al*., 2018). Intelligent assets and connectivity are fundamental to operationalize circular economy (MORLET *et al.,* 2016), specially by optimizing forward material flows and enabling reverse material flows (PAGOROPOULOS *et al*., 2017). Their main functionalities are suggested by Bressanelli et al., (2018) as: improvement of product design, attraction of target customers, monitoring and tracking of product activity, offering technical support, providing preventive and predictive maintenance, optimizing the product usage, upgrading the product, enhancing renovation and end-of-life activities.

Still according to Jun et al. (2007), IoT through sensors collecting data from the usage phase can help to improve product design and to better meet customer's needs (BAINES; LIGHTFOOT, 2014). Knowing how customers are using the installed products can also assist companies to improve marketing activities and target new customers (RUST; HUANG, 2014). Digitalization may also help companies to provide better technical support, repair, spare parts management and provide preventive and predictive maintenance through big data and analytics (BAINES; LIGHTFOOT, 2014; RYMASZEWSKA *et al.,* 2017). Furthermore, in the case of smart products, consultancy services may be offered to: optimize usage phase, reduce energy consumption, and upgrade digital elements (RYMASZEWSKA *et al.,* 2017; ARDOLINO *et al.,* 2018). Regarding end-of-life, companies can access real-time product location and condition (FRANCO, 2017), for a better execution of collection, refurbishment, remanufacturing and recycling activities (LEWANDOWSKI, 2016; BRESSANELLI *et al.*, 2018).

However, the mentioned technological functionalities are mostly related to the middle of life (MOL-product use, service and repair) (WUEST; WELLSANDT, 2016). Organizations investing in digital technologies focusing on closing the loop need to make efforts at the beginning of life (BOL-design, production and distribution), such as design-for-remanufacturing; design-for-recycling (KHAN *et al*., 2018;GO *et al*., 2015; BAKKER *et al.*, 2014), or specifically at the end of life (EOL –reuse, remanufacturing, recycling, disposal) through reverse logistics (KUMAR; PUTNAM, 2008).

Table 1 summarizes the literature founding this research.

Table 1 – Literature Background synthesis

Main Subject	Related Theme	References	Specific Themes	Synthesis
Lifecycle	Lifecycle	Jun et al.(2007); Wang et al. (2011); Wuest and Wellsandt,(2016); Khan et al., (2018);	Beginning of Life Middle of Life End of Life	Each lifecycle stage encompasses specific activities, different levels of interdependency and engagement intensity among stakeholders. PSS migrates the “life cycle gate” to post-production phases, intensifying provider stewardship to MOL and EOL stages.
Sustainability	Triple Bottom Line	Elkington (1997); Ghisellini et al.(2016); Kristensen and Remmen (2019)	Economic Social Environment	Triple bottom line is a simplified approach to define sustainability, in which economic, social and environmental aspects of the business should be balanced and improved together.
	Circular Economy	Ellen MacArthur Foundation (2012); Kane et al., (2018) Geissdoerfer et al. (2017) ; Kjaer and Pigosso (2018); Doni et al., (2019); Reike et al.(2018)	Reuse – redistribute Refurbish – remanufacturing Recycle Share Dematerialize	The circular economy technical cycles are interconnected throughout the business lifecycle; from the very extreme, users “share”, sometimes “dematerialized” business, until the service providers “maintain/prolong”, going to manufactures “reuse - redistribute” and parts manufacturers “refurbish - remanufacture” and “recycle” in cascade interdependent relationships focusing on sustainable aspects.
Digitalization	Digital Technologies	Bressanelli et al. (2018); Pagoropoulos et al. (2017); Jun et al. (2007); Ardolino et al., (2018)	IoT – Internet of Things ICT*- Communication Technologies	The incorporation of ICT is considered key-aspects to the design and development of any business relationship; in this study, they are considered moderating factors for the good performance/management of any medical devices (currently all connected to the internet) or positively influencing the guarantee of contractual aspects to accomplish sustainable servitisation

Servitization	Product Service Systems	Kjaer et al. (2016); Kjaer and Pigosso (2018); Tukker (2004); Annarelli et al., (2016)	PO -Product-Oriented UO-Use Oriented RO-Result-Oriented	The level of servitization adopted herein ranges from the less servitized product-oriented PSS (with maintenance and complimentary services offered with the product sale), to the most servitized: use and result-oriented PSS (dematerialized and performance lead offer).

10.3 Research Methods

Multiple case studies are particularly useful due to the exploratory nature of this research (EISENHARDT, 1989; EISENHARDT; GRAEBNER, 2007; YIN, 2013), which concerns the embedded circular economy technical cycles components (GUZZO *et al.,* 2019) in healthcare product service systems (PEREIRA; KREYE; CARVALHO, 2019) performed in Brazil and in the UK. Case studies are specially indicated for an in-depth analysis and investigation of complex social phenomena, such as the healthcare area, which is a very context-specific research field. Despite the issue of generalisability, case studies allow a holistic analysis of contemporary aspects performed when the boundary of the phenomenon of interest is unclear (YIN, 2013).

10.3.1 Sampling and data collection

Theoretical sampling is performed, rather than choosing a representative sample of cases (EISENHARDT; GRAEBNER, 2007). The unity of analysis is the organizations in the PSS healthcare network, which gather multiple perspectives of the empirical situation of CE aspects in the healthcare field. The selection criteria were guided by choosing different organizations with distinct roles and perspectives, such as equipment suppliers, hospitals, middleware and software developers, regulators agencies, consulting companies and waste management companies that compose a selected stakeholders' network. To understand contextual issues, different countries were investigated: Brazil and the UK. Note that the same companies' roles were chosen in Brazil and in the UK to identify the main insights between those countries.

The combination of primary data collection (semi structured interviews) and other information sources (public and internal documents) improve understanding on the area (SIGGELKOW, 2007) and also help to mitigate the bias that multiple case studies may impose (YIN, 2013). The main data sources are semi-structured interviews, which were recorded, once agreed by the interviewees, transcribed and validated for further analysis.

The literature analysis described in the previous section grounded the research instrument aligned with the theoretical background (Table 1), which allowed us to trace different aspects of organizations' embedded in the PSS network while identifying the circular economy advances and challenges in the healthcare field.

The interviews instrument were divided into three parts (BOL, MOL and EOL) for "photographing" the most evident arrangements between the stakeholders within each main phase of a PSS. The first part, BOL, was related to acquisition aspects of a PSS in healthcare. The second part, MOL, was focused on the PSS operationalization, digital technologies, maintenance and overall sustainability related-outcomes. The third, EOL, connected circular economy in terms of CE technical cycles and sustainability. The main selection criterion for each interviewee was a broader business knowledge level (not limited to his/her own department). Most hold leadership position as managers, or in the case of small-sized companies, are CEOs. The number of employees was the main criterion for classifying the company size into: small (less than 10), medium (between 11 and 1,000) and large (more than 1,000). Table 2 and Table 3 show an overview of the sixteen organizations and 50 roles of interviewees that participated in this research.

Table 2 - Overview of case studies in Brazil (26 interviewees)

#	Case	Description	B2B B2C	Type	Size	Interviewees	Interviewees' roles
1	#A-BR	Public /Research Hospital	B2B B2C	Service	L	8	Clinical Engineering Director, Clinical Engineering Manager, Imaging Equipment Manager; Contracts Manager; Laboratory Physician /Manager; Maintenance Manager, Equipment Disposal Manager; Waste Disposal/Quality Manager
2	#B-BR"	Large Manufacturers	B2B	Manufacturing/ Service	L	5	Service Operations Manager-Latin America; Project/Product Manager-Latin America; Services Director-Latin America; Product/Service Quality Manager-Latin America; Service Manager- Brazil
3	#C-BR	Large Manufacturers	B2B	Manufacturing/ Service	L	5	Head of Enterprise Service Solutions; Service Director Customer Service Engineer Manager Products Manager Sales Manager
4	#D-BR	Digital Enablers	B2B	Manufacturing/ Service	S	1	Executive Director -CEO
5	#E-BR	Digital Enablers	B2B	Manufacturing/ Service	S	1	Executive Director-CEO
6	#F-BR	Consulting Company	B2B	Services	M	2	Executive Director -CEO Project Engineer Account Leader
7	#G-BR	Government Regulation Agency	B2B	Regulatory Agency	L	3	Technology and Health Products General-Manager; Implantable Materials Coordinator; Clinical Research in Health Products Coordinator;
8	#H-BR	Waste Management Company	B2B	Service	M	1	Market General-Manager

Table 3 - Overview of case studies in UK (24 interviewees)

#	Case	Description	B2B B2C	Type	Size	Interviewees	Interviewees' roles
1	#A-UK	Public /Research Hospital	B2B B2C	Service	L	7	Procurement Manager Intelligency Blood Analysis Lab Lead Investment Strategic Planning Manager Energy, Sustainability and Facilities Manager Laboratory Physician /Manager; Clinical Engineering Director, Business Project Manager Lead
2	#B-UK	Large Manufacturers	B2B	Manufacturing/ Service	L	4	Sales Manager Account Manager Sales Manager Lead Project Account Manager
3	#C-UK	Large Manufacturers	B2B	Manufacturing/ Service	L	4	Lead Business Designer Engineer Lead HCS for WEA region Services Director Strategic Project Manager
4	#D-UK	Digital Enablers	B2B	Manufacturing/ Service	S	2	Performance Manager Executive Director -CEO
5	#E-UK	Digital Enablers	B2B	Services	M	1	Strategic Business Manager
6	#F-UK	Consulting Company	B2B	Service	M	3	Lead Business Manager Project Engineer Account Lead Latin America Director;
7	#G-UK	Government Regulation Agency	B2B	Regulatory Agency	L	2	Green Procurement Manager Lead of Strategic Planning
8	#H-UK	Waste Management Company	B2B	Service	M	1	General-Manager

10.3.2 Data Analysis

The content analysis was performed on the transcribed interviews, which were coded and further explored (frequency counts and cross-tabulations) grounding the interpretation of results (DURIAU; REGER; PFARRER, 2007). A computer-aided approach was used with the software NVIVO (BAZELEY; JACKSON, 2013), to perform the coding and further in-depth analysis of interview data, enabling insights by the aggregation of information towards the most relevant aspects. The data were worked from the ground up (YIN, 2013). When the data were examined, many concepts emerged, following the grounded theory methodology proposed by Corbin and Strauss (1996), since it is an exploratory approach and no explicit testable hypothesis exist.

The coding of data followed the stages of each interview and included three blocks of themes, according to Table 1, derived from the literature background. The empirical case results were then triangulated with the literature and a framework was proposed combining insights from the case studies and the literature analysis.

To show an overview of such a complex environment and eventually develop improvements in understanding, as suggested by Eisenhardt and Graebner (2007, p. 29), it is appropriate to summarize the evidence in sections. Every part of the theory is demonstrated by evidence from at least some of the cases, but also providing multiple perspectives from the different actors, as detailed. The evidences are presented in the next section through Lifecycle Stages within Healthcare.

10.4 Research Results

10.4.1 BOL-Beginning of Life

The Beginning of Life of a product service system, according to Jun et al (2007) corresponds to the product activities of market research, design and manufacturing and the service activities of demands identification, concept development and service modelling and realization planning (AURICH; FUCHS; WAGENKNECHT, 2006). According to Wang et al (2011) the sustainability potential of a PSS relies on "system optimisation of multi-life cycle."

10.4.1.1 Sustainability influence and the procurement in Brazil and in the UK

In this stage, environmental aspects regarding equipment operation, such as equipment waste, energy, water and other consumables should be taken into consideration, but in Brazil, and especially in the selected hospital case study, those aspects are currently considered peripheral, not influencing the choice of the manufacturer as much as price and complementary conditions do. In fact, during a tendering process, some fundamental aspects are taken into consideration, such as ISO 14000, but there are not specific clauses regarding sustainability issues (disposal, take-back, packaging, water aspects, and so on). According to the *Imaging Equipment Manager – Case A-BR*, *"environmental aspects are something that do not have any appeal in the area. To make an acquisition, I do not know where to start regarding these…the efficiency requirements and manufacturers do not exploit this issue much. [..] So it turns out that descriptive memorials (to procurement) do not charge for resource efficiency/ more sustainable products, there is a gap in that regard".*

Although manufacturers advocate the sustainability of their equipment, regarding ISO 14000 and so on, the average knowledge on the importance of these aspects are still marginal among most of the manufacturer's interviewees. Yet, according *to* the *Service Director – Case C-BR*, there is a lack of commitment with sustainability issues on the part of the most of Brazilian contractors: *"For the vast majority (sustainability issues) is a passing thing. […]it's a maturing process, actually […] we do not have much choice. […] innovations are increasingly coming from software, systems issues, and sustainability. It's something we believein, but that is still* *lowly valued by most of the Brazilian market."*

To foster circularity, at the design stage, the manufacturer needs to insert specific aspects in the product/service conception, such as design for durability, for reliability, for product attachment, for ease of maintenance and repair, for upgradability, for disassembly and reassembly, as well as part standardization (KHAN et al., 2018). Yet, most of the medical equipment in the country is imported (circa 75% of the total market) (PWC BRASIL, 2013), for that reason, those design aspects are defined in the original manufacturer's headquarters.

In the UK hospital (case A-UK), however, since 2017, there has been a dedicated sustainability team, and their general manager is often invited to collaborate in the descriptive memorials that precede procurement activities, as well as during the suppliers selection process. In fact, there is a special section in the bidding process that corresponds to 5% of the weight of the whole contract, only focusing on sustainability-related aspects. Some examples of scored aspects are: team waste segregation training; carbon and other greenhouse emissions reduction, sustainable development management plan; minimization of the environmental impacts associated with travel to hospital sites and delivery of goods and services (e.g. minimization of traffic burden - more efficiently planned deliveries), following the hazardous substances regulation (2009); waste electronic and electrical equipment regulation (2012), having Environmental Management System that is consistent with ISO 14001: EMS: 2004, EMAS, or a demonstrated equivalent standard, packaging origin and recyclability level, and so on. *According to the Energy, Sustainability and Facilities Manager case A-UK "every big organisation has a way of buying stuff and you need to be able to influence a way of buying stuff so that the stuff that gets bought has the appropriate KPI system on it; that's sustainability."*

10.4.1.2 *Second-hand equipment in Brazil and in the UK*

Second-hand medical devices are those which are already on the market and have been 'preowned' and used and that are subsequently 'sold on' for the same continued use. It is noteworthy regarding a circular economy practice that, depending on the financial availability, small and medium clinics sometimes use second-hand equipment, even though this repair and reuse process (by others than the original manufacturer or third parties designated by them) is currently forbidden in the country (ANVISA, 2012). The market customer-provider business relationships have adapted to create new businesses with second-hand equipment, and that represent a point of tension and conflict within the Brazilian healthcare ecosystem. *"In Brazil, used product trading is prohibited. We know that there is a lot of irregular trade. It is even the subject of inspections, interventions and proper sanctions."* The *Technology and Health*

Products General-Manager– Case G-BR

Brazilian Regulation also states a restriction in the use of six hazardous substances in the manufacture of electrical and electronic products: lead, mercury, cadmium, chromium and flame retardants (ANVISA, 2012), according to RhOS and WEEE directives *to* complement the law of solid waste (Law nº 12.305/10).

In the UK, the Medicines and Healthcare products Regulatory Agency (MHRA) is a government body that brings together the functions of the Medicines Control Agency (MCA) and the Medical Devices Agency (MDA); this body would correspond to ANVISA in Brazil. Differently from Brazil, second-hand products in the UK are regulated and frequent, since the average of health equipment use phase is lower. According to the MHRA (2015), for second-hand trade, usage and service history should always be available for prospective purchasers before sale and then supplied with the device, at the point of sale.

10.4.2 MOL-Middle of Life

MOL corresponds to the distribution, usage, service and repair stage (JUN; KIRITSIS; XIROUCHAKIS, 2007). Once installed, as the equipment will occasionally undergo maintenance and also a series of complementary services, depending on the contractual agreements established between customers and providers during the BOL phase. Some examples of services in this phase are (Kreye et al., 2015; Aurich et al., 2006): corrective/preventative maintenance; quality insurance; security inspections and support; product upgrades; telephone support; emergency calls; spare parts supply; guaranteed response time; hardware and software upgrades; extended asset uptime; after office hour support; technical training; performance guarantee, performance monitoring, report and adjustments, and many others that, if well conducted, can prolong equipment life.

One of the main consequences of the activities performed in MOL (either by original manufacturers, or by third parties) is better efficiency and overall performance through continuous monitoring of asset KPIs, aligned with the first CE technical cycle (reduce). Adding to that, the prolonged life of the asset is also an expected consequence of MOL activities, mainly related to corrective, preventive and predictive maintenance, as well as upgradability (in software and sometimes hardware update, module exchange, and so on), which is the second component of the CE technical cycles (repair)(MACARTHUR, 2013).

10.4.2.1 *Second-Hand Equipment 'dealers' or original manufacturer: a repair decision*

The cannibalization of equipment performed by the second-hand market "dealers" is also a regular discussion within the healthcare market, according to a Maintenance Manager - Case #A, *"Currently, we know former original manufacturer workers that charge cheaper than the original manufacturer average [...] In fact, they have equipment just like ours that is used only for dismantling. When some part in mine breaks, he brings it and replaces it" However, for complex equipment, such as MRI, we have to maintain with the original manufacturer, because they are not allowed to buy new components."* The actual business configuration confirms Wise and Baumgartner's (1999) theory, "Delivering a great product is not enough to get the loyalty of a customer. You must offer a combination of services that minimizes the overall costs." And also, indirectly, those second-hand dealers contribute to the "reuse" technical cycle of circular economy.

10.4.2.2 *Modularization in Repair process*

Modular architecture has been identified as a technique that significantly enhances product life cycle management including ease of product disassembly, thereby improving product serviceability and cleaning processes. (FADEYI; MONPLAISIR; AGUWA, 2017)

Most healthcare equipment maintenance is based on changing modules, to make MTTR (medium time to repair) as short as possible, since long stops impair the user's calendar of exams and also due to upgradability issues, since software and even hardware updates require better infrastructure for system improvement. According to the *Clinical Engineer – Case #A-UK,* the upgradability of an equipment is defined from the very beginning of the manufacturer-contractor relationship, belonging to BOL requirements in contractual agreements*: "Software needs to be updated and their use must be assured safely for the benefit of the patient".* Occasionally this manufacturer's strategy may cause the generation of excess waste, whereas helping to intensify the equipment use and to extend its life cycle. The waste generated in maintenance activities (old broken parts/modules) is usually disposed of in recycling bins, either in the contractor's waste disposal or in the manufacturer's one. However, in the case of electronic boards, they are replaced and re-sent to the headquarters to refurbishing, reuse or eventually recycling processes, due to their intrinsic economic value.

According to a Service *Director –Case#B "we increasingly use module switching[...]" Hence, more and more newer machines have a hardware architecture aimed at replacing modules.*

[…] because (of the need) of greater computational power, because they generate many more images with better quality in less time [...]; in some situations, it turns out that this side of working with modules may be more expensive for the customer.” About the disposal of old parts coming from maintenance activities *the Customer Service Engineer Manager-case #C* stresses that mostly, there is not a determined rule: *“We end up returning larger parts to the company. We end up throwing smaller pieces in the customer's own garbage; the customer makes the separation. When the pieces are larger, the piece label instructs whether it is a part that is returnable to the headquarters or not.”* Furthermore, regarding sustainability, most interviewees suggested that besides having ISO 14000 certification, *“[..] which obliges us to give correct destination to all the material we use, procedurally speaking”, according to the Service Manager- Brazil-case #B,* very few things regarding sustainability are stressed in ordinary activities.

10.4.2.3 Original Manufacturer’s digitalization and contractor’s perception

Within the MOL phase, the importance of digitalization is outstanding. Even tough in the industry, digital remote monitoring is intensely used due to IoT, bid data, analytics and cloud computing (ANNARELLI; BATTISTELLA; NONINO, 2019), the use of those technologies for healthcare equipment is still limited. Although many customers recognize that manufacturers could have a more proactive role in detecting equipment misalignment remotely, most complain that there is not such positioning. *“I take ten monitoring parameters in a resonance by myself (internal digital solutions with the help of a startup)... It must be over 100. So sharing this information with us would be very useful. Currently, the model is heavily based on the sale of this and other services, which ends up being unfeasible and unaffordable for us.” Imaging Equipment Manager – Case #A*

On the other hand, manufacturers recognize the gaps they are still facing *“we are in the process of moving from a more reactive posture to a more proactive one by using these online monitoring platforms. […]it's a growing trend […].Yet, I think it is still crawling…”Customer Service Engineer Manager-Case# C.* Also, another issue is the amount of information prevenient from these equipment; they are so large that providers mention that it is even difficult to filter what kind of information is really important; according to the Service Director – Case # B: *“Honestly, they (proactive actions) do not always happen, because it's a system that generates a lot of alerts.[…]. We can warn about an alert that is happening and may have a problem in the future or, for example, notify the customer that the temperature of the magneto* *is rising and this can cause a loss of helium […]. So in some actions, we can be preventive. But not to 100% of the things that happen. But in fact our intention for the future is to expand those actions; that this, identification of standards, and of proactive maintenance, will begin to increase."*

10.4.2.4 *Sustainability consequences of digitalization*

Many customers' calls are, however, assisted by online experts that can conduct a distance check on basic equipment parameters*"[…] the online centre is the first service provision as a standard procedure.[…] the engineer, when he goes (to the customer), when it is necessary to perform a corrective maintenance, he has already the equipment pre-diagnosed. Eventually, he even takes the necessary equipment spare part (with him). […] we end up being more efficient, reducing the equipment downtime, consequently increasing the revenue of our customers and reducing costs." Service Operations Manager - Case# B.* At the same time, occasional extra benefits from remote monitoring is emphasized by the *Project/Product Manager-case #C "[…] In fact, the indirect benefit is to reduce travel costs, engineering time, CO2 emissions due to long hours in traffic, energy, material resources for extra transportation. Another indirect benefit is with the institution, by having faster equipment diagnosis, and not having to wait for a person to cross a city like São Paulo, to then identify any maintenance problem and then solve it in a second visit (minimally)."*

Still regarding the cons of distance monitoring, the *Service Manager-Case # B emphasizes" […] we do not give visibility to the things we do remotely. This is the counterpoint to technology platforms that in fact you do not need to be there; you access remotely, you act unnoticed. It becomes difficult for you to show the value to your client. So if you do not work on the communication, the customer may find that: "Why making a maintenance contract… the equipment does not break ... No one has ever come here, etc." And we're actually working behind the scenes."* However, it should be stressed that in maintenance full contracts, the manufacturer's intervention is admittedly tighter*, "they do remote monitoring and sometimes they even call: "Oh, the pressure, the temperature is not ok" ... Because it is a full contract, and they are the ones that will bear the loss of the coverage. So they actually need to have great control and be efficient." Imaging Manager – Case # A*

Towards a more strategic thinking, the Executive Director –Case # F brings insights about the main goal of every advanced technology in the global overview of the healthcare sector. *"Of course, there is technology available for monitoring, technology available to do everything in a cloud, almost 100% of suppliers, especially of large medical equipment, offer some equipment* *available. However, what the market offers is focused on the interest of those who want to sell and guarantee a sustainable sales strategy that ensures services, sale of materials, parts, and finally a maintenance contract that surrounds the seller's profitability than an end-user focused strategy, which is in fact, the patient"*. This insight refers to the main goal of the whole sector that should be led by better experience opportunities to the patient.

10.4.2.5 *Barriers to Monitoring Performance*

Considering digitalization, besides offering a new set of opportunities to the organizations, there are innumerous barriers to its implementation, due to the internal resistance in opening up their "information silos" and the poor understanding of cooperation with other offices and data sharing. (ANNARELLI; BATTISTELLA; NONINO, 2019). One of the reasons why contractors were pushed to develop internal solutions. The *Imaging Equipment Manager – Case #A* explained: *" [...] we have developed a platform, with a startup and an internal partner to get information from the equipment. So, for example, [...] we monitor these parameters here for MRI. [...] which are essential: temperature and humidity of the room; cold water temperature for the cryogenic stream; compressor current; the percentage that is the level of helium within the resonance; the magneto pressure that is important; and in the examination room temperature and humidity. It is a simple device [...] if it is green, it is ok, inside the parameter, [...] If it is yellow, it is outside, near the limit [...]. If it gets too bad, it turns red. Now to get that out of there, we had to get into the machine (ourselves) and take it off ... Pull the sensor because manufacturers do not open anything at all. It was kind of hacked. I am glad now we can perform and systematize those solutions"*

Another barrier regarding monitoring aspects is the uncomfortable aspect of having any misalignment shown to anyone in an updated online monitoring system. According to *executive manager of case #D-BR "one of my potential clients (a large private hospital) clearly complained[…]"we do not like anyone to look at those indicators […] because the screen turns red, when the air conditioning is not settled correctly […]this generates trouble for us". […] they do not think it can generate problem for the patient, or for the equipment. They think ... in how maintenance of clinical engineering will be evaluated. So they'd rather not have the monitoring system, and hide everything behind the wall". […] they need to change their mentality; sometimes you see that it is not a cool thing."*

Also according to the Executive Director-Case # E-BR, access restrictions in implementing digital platforms to perform monitoring can be considered a special issue, due to the excessive protection of hospital networks. *"Inside the hospital, the IT part is the worst part you have. Why? They limit your access to everything. It is difficult to open anything and send the data anywhere. So we have to develop a system that predicts: voltage drop, network drop, if the network stops, you have to send by SMS.[…]so the system needs firewall, it needs redundancy. […] If it all fails, it has to store all the data; when it comes back, it has to download everything not to lose any data that has been collected and so on…"*

10.4.3 EOL-End of Life

EOL in PSS can be defined as a post-use alternative to the product, or its components and parts. Handling EOL products components may include one or more of the options: reuse, remanufacture, refurbish, recycling, incineration, landfill, and special handling (CONG; ZHAO; SUTHERLAND, 2017). Among these EOL options, reusing and remanufacturing offer better opportunities to reclaim money, energy, and material investments (SUTHERLAND; GUNTER; WEINMANN, 2002). However, product life cycle performance is largely influenced by the decisions made at the early phase of product development (FADEYI; MONPLAISIR; AGUWA, 2017), such as modular architecture to ease product disassembly, to improve product serviceability and cleaning processes. Adding to that, consumer decisions during the use phase, such as repair, pass on or throw away products due to post-warranty maintenance costs and product functionality directly affects a product life span and, as a consequence, the rate of waste generation. (SHOKOHYAR; MANSOUR; KARIMI, 2014)
Once the equipment end of service is decreed, and it belongs to the customer, the latter should decide if he wants to have it replaced with an upgraded equipment of the same brand, or to acquire a different brand. In public institutions, such as Case #A-BR and Case A-UK, they go through tendering processes and the best offer is taken into consideration, regarding total cost (product and service through the whole equipment useful life). Keeping the same brand, the manufacturer himself sends the old equipment to a waste management company that will perform the environmentally adequate disposal (see next section*)*. In the case of acquiring a new brand, the customer himself has to manage the equipment end of life (and paying for that). In the case of RO-PSS, or UO-PSS, in which the manufacturer owns the equipment, the equipment is usually evaluated in the manufacturer's repair shop. In case the equipment can undergo an upgrade, or can have the old "used/broken" parts replaced, they are repaired and reused in another contract. In other cases, selected parts are sent back to the headquarter for

further component analysis and for recovering worthy materials from special electronic boards or for occasional remanufacturing. In that case, a waste management company performs the scrapping of the remaining equipment structure and components.

10.4.3.1 The "zero-landfill" End of Life

Some certified companies deal with the proper final disposal process of healthcare equipment, in which the goal should be to send zero materials to a landfill aligned with sustainability principles. Their main offer is the proper discard, regarding environmental aspects, and the documentation of scrapping material tracking. The main reason to contract these companies is that according to [whom?]*: "The company (equipment owner) does not want its equipment to be cannibalized and the parts to be reused or even the whole equipment, sometimes the whole equipment is working, it is only obsolete. So we guarantee the equipment destruction and of its components as well."* The process is only viable due to partnerships with the cement industry, metal recovery industry, plastic recycling companies and so on. Since the income generation with the selling of recycled materials is insufficient to run the business, this service is also charged and payed for either by the manufacturer or by the contractor. *"[...] the greatest volume comes from manufacturers. And the culture of proper treatment is also greater today on the part of manufacturers. In general, they are multinational, with departments of sustainability, environment, quality, and the like. Hospitals, we have noticed today an exponential growth, of great hospital networks that operate in the country, for solutions for equipment in general. And then when I say equipment, we are talking from the administrative computer to the medical-hospital equipment". Market General-Manager – case #H-BR*

A synthesis of the EOL procedures for healthcare equipment can be explained into XSteps: (1) Equipment autoclave before disassembly, which is usually manual. The autoclave decontaminates, treats biological risk, pathological risk, injecting steam at high pressure and temperature (140 degrees - 150 degrees) from 15 to 20 min;(2) Segregation: Once decontaminated, we have two processes: either a mechanical descrambling which is a gross grinding and separation, then a mechanical separation phase, or by magnets, or other separation processes, and then a manual refinement; (3) After this reverse manufacturing, disassembling, disaggregation and components classification. (4) Final destination with partner companies: recycling of plastic, co processing in cement factory (to use as fuel), metal recycling and so on. *According to General-Manager – case #H-UK:" Electronic boards are crushed, ground and shipped out for recovering precious metals. And in the end we offer a complete traceability* *report with the detailing of the process: the day the equipment arrived, the documentation, and so on. We also announce the whole mass, e.g. from 5000 kg equipment, 1000 kg were plastic for supplier A; 500kg of metal for supplier B, [...] and we document the legal destination from the point of view of environmental legislation, and zero landfill."*

10.4.3.2 Equipment tracking and End of Life

An interesting issue that has emerged for the case of PO-PSS is that, although manufacturers are expected to keep track of the equipment and clients they sell it to, first because of the interest in keeping a clients' portfolio, but also because they are theoretically co-responsible for equipment end of life, they do not. Additionally, there is not a sanction regarding lack of EOL involvement by the original manufacturers in the country; they are not legally forced to perform those actions yet, instead, this gap is being used towards creating new businesses, the second-hand equipment market nurtured by small clinics and private hospitals. Besides "payed services" of waste management companies, junkyards may also accept the used equipment, and even pay a little for them. They will not provide the most "environmentally correct" end of life for the equipment, but will certainly make the highest profit possible of its disassembled parts, contributing to the reuse and refurbish technical cycles of CE. According to the *Market General-Manager – case #H-BR "There is a giant network of small and micro enterprises that are interested in removing the equipment from their "owners" for free or even pay for it. But in , these companies take advantage of what has value and what has no value, nobody knows the destination given."*

10.4.3.3 Co-responsibility

Equipment manufacturers can be considered some of the large players of the healthcare business, but they are certainly not the leading ones. As important actors, they connect a variety of stakeholders and when taking part in a trading business with any hospital or clinic, they need to make sure their image represents politically correct actions before the society and the government. The same thing happens to the waste that may be reused from hospitals, such as beds, sheets, coats, overdue remedies. The entities' names and co-responsibility before society is so valuable, since it is important to protect their social image, in the case of any injuries or diseases that may occasionally happen. Therefore, anything should be properly disposed of, according to the *Waste Disposal/Quality Manager – Case # A: "you are co-responsible in the whole process. You may hire a company to provide bed service knowing that it renews the* *mattress, taking them away from time to time, but the cycle has to close. If the company discards them in an inappropriate location ... you remain co-responsible [..] so when you hire, you need all this very well aligned."*

In this sense, although the Brazilian law strongly advises and stimulates partnering with the labour of cooperatives, original manufacturers and certified waste management organizations prefer not to work with them. Most of those cooperatives are composed by deprived population workers. Yet, according to the *Market General-Manager – case #H: "[...]some natural issues regarding cooperatives are labour problems, occupational safety, technical adequacy. Our clients do not even allow us to work with cooperatives in most cases. [...] in fact, we are getting along really well with cooperatives, (within the reverse logistics of packaging) also because the national solid waste policy requires the reverse logistics system to involve cooperatives[...]yet there are still many grey technical questions."*

10.4.3.4 *Repair in Brazil, Refurbishing in the Headquarters*

The concept of remanufacture and refurbish "denotes a more comprehensive overhaul of products by replacing parts that are failing or likely to do so soon" (LÜDEKE-FREUND; GOLD; BOCKEN, 2019). The first ensures that products comply with the performance specifications of the original equipment manufacturer through the wholesale restoration and replacement of main components (DIALLO et al., 2017). Refurbish means to fix a used equipment with its own or with other used pieces (HARMS; LINTON, 2016), it is the "process of disassembling, cleaning, inspecting, repairing, replacing, and reassembling the components of a part or product to like-new condition"(THORN; ROGERSON, 2002).

Repair centres of large equipment manufacturers' players, are allowed to repair or to remanufacture, using imported new parts and new components (since there is no healthcare equipment manufacturing in Brazil). However, it is common that "broken modules" with electronic boards are sent back to the headquarters. In those countries, the regulation allows the commercialization of refurbished materials (used parts accordingly repaired and re-used). Note that electronic boards are more valuable when repaired "as electronic boards" than when merely recycled components. In addition, headquarters research quality issues based on those evidences (broken pieces). According to the Service *Director –Case#C-BR [...]we have to return some things to Germany, because they perform an analysis job there, and they also work on recovering the pieces and some materials."* Yet, according to the *Repair Shop Manager – case # B-BR"[...]. there is a range of parts that they return to the headquarter in Switzerland.*

[...] there is a remanufacturing process that is allowed there. […]usually they are pieces that have a metallic structure [...] or electronic boards that are extremely expensive ... for example ... we have a piece that we call a cooler, all made of aluminium. However, what brings trouble to it is a tiny, super-cheap piece. The whole module costs circa $ 5,000; the problem-piece costs $ 100".

According to regulations in Brazil, only new equipment and new parts are allowed to be imported, differently from the UK and other European countries. Even tough remanufacturing and refurbishing processes are legally not allowed, they happen within the second-hand equipment market; regulatory agencies face increasing challenges to inspect and to apply the possible sanctions. In the UK, fully refurbished medical devices are considered to mean that a device has been completely rebuilt / made as new from used devices and is assigned a new 'useful life', with the requirements of the medical device regulations.

According to Anvisa, there is an attempt to create a certification for the companies that intend to work with the remanufacturing and reuse of healthcare equipment. In that case, the company would proceed just like in the UK. The companies would guarantee adequate technical body registration among others to act with responsibility on the expected work. However, it is still under discussion with a diversity of stakeholders with no estimated deadline, postponing the improvement of the Brazilian contribution to CE. The Technology and Health Products General-Manager – Case #G-BR stresses that "*the trade in of used equipment is being worked on [..]at the time Rdc 25 came into force (2001), it was considered enough to control the sanitary risk of the used products trade in.[…] currently we are favourable. As long as it meets the prerequisites for safety, proper maintenance, technical evaluation of the original manufacturer, or of a qualified engineer with registration in CREA (engineering association council) and so on."*

10.5 Discussion

10.5.1 Pathways towards CE

The transition from "old school" or linear thinking manufacturing to a circular economy promoting society, according to the evidences from the 16 case studies performed in Brazil and in the UK is driven by both company-driven pathways and through the regulation-driven pathway (see Figure 1).

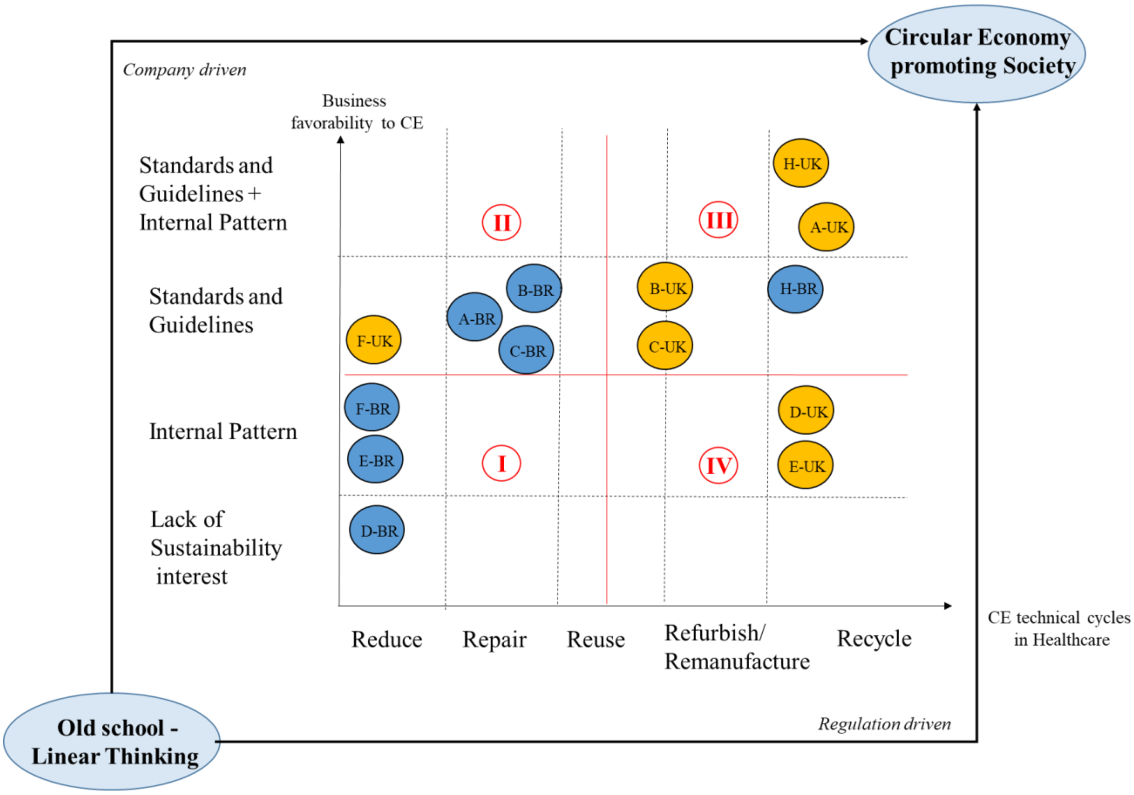

Figure 1: Pathway towards CE: business favourability to CE and CE technical cycles

Figure 1 represents the summary of the performed cases, with their allocation according to the business favourability to CE (y axis) and CE technical cycles (x axis). Both are ascendant, which means the gradation is increasing toward the arrows. Most Brazilian companies are located in regions I and II, in which the CE technical cycles are limited between reduce and repair. Adding to that, no case reached the top of business favourability to CE, when standards and guidelines guide the companies' actions together with the internal pattern procedures. No positioning of Brazilian companies in the reuse and refurbish/remanufacture columns is explained for the direct effect of the current regulation in Brazil, which hinders remanufacture and forbids reuse (second-hand equipment). Waste Management Company is the only one located within region III in the recycle column guided by standards and guidelines, which means they strictly follow the "rules", evidencing the main goal of that company. Regulatory Agencies from UK and Brazil were not allocated, due to their lack of business and CE technical cycle-oriented goals. Most UK companies are allocated in regions III and IV, because of their reuse, refurbish/remanufacture and recycling practices, according to the CE technical cycles improvement gradation. In addition, CE guidelines and guidelines with differentiated internal pattern inspire most of the UK interviewees.

Comparing both countries maturity regarding CE, regulation in Brazil limits further CE technical cycles development, while the UK regulation is more updated and fosters CE, probably due to the carbon emissions target influence.

Regulatory measures are developed to organize the involved stakeholders once any new business activity is being performed (case of second-hand and refurbishing activities in Brazil). This stresses the issue about how fast policy makers can act and how long the pathway to put regulations into force is.

The companies that provide PSS for healthcare in Brazil are mostly large international and well-known worldwide organizations. They need to watch over their image and guarantee social responsiveness regarding a proper EOL procedure, which becomes their main driver to implement CE by hiring waste management companies. Furthermore, in the case of any inspection from regulatory entities, their equipment traceability, provided by third party waste management, protects them. In turn, in PO-PSS, CE is practiced by a need coming from the PSS customers, and scrap “dealers” as a business solution that emerges from the stakeholders’ configuration and is led by thousands of small and medium enterprises (SMEs). Therefore, CE is mostly practiced through reusing, repairing and refurbishing either the completely used equipment (nurturing a second-hand market) or collecting old parts/components of used/obsolete equipment (configuring a parallel market of maintenance services). Note that only original manufacturers can require and import new spare parts and components to replace broken ones (most health equipment in Brazil is imported), which is the main condition that limits this parallel market deployment.

10.5.2 Closing the loops in healthcare PSSs

Circularity within healthcare PSSs should be thought of in an integrative approach throughout the whole PSS lifecycle. Figure 2 shows the main groups of processes of each life cycle stage from a focal firm perspective (PSS provider) with emphasis on 6 moments in which CE technical cycle concepts play a special role. The main stakeholders are represented around the focal firm and the steps in which they interact are represented by the numbers next to each group of stakeholders.

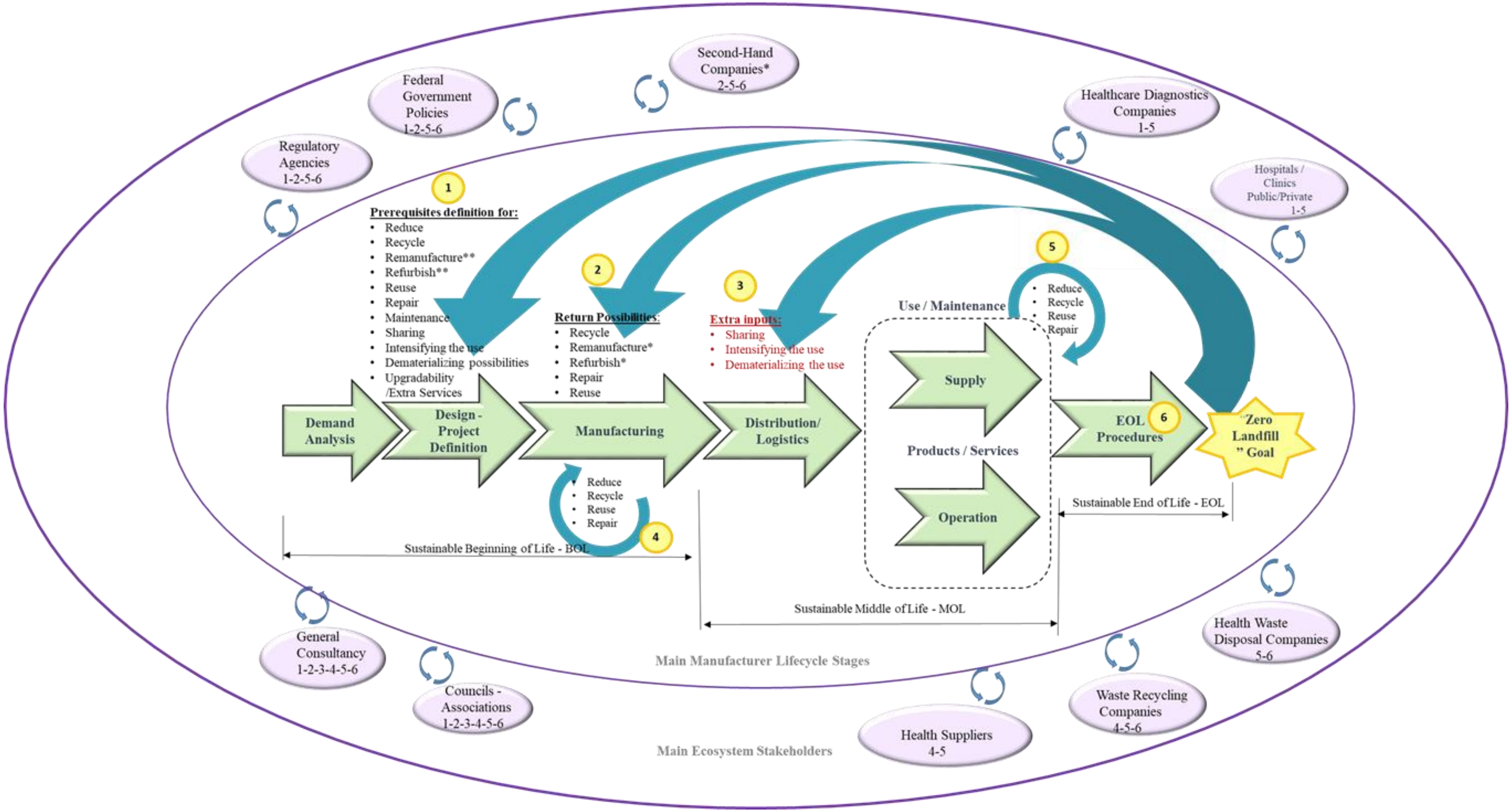

Figure 2: Focal firm (PSS Provider) life cycle main processes and main stakeholders with their respective CE technical cycle interactions (adapted from MacArthur, 2013 and Lüdeke-freund et al., 2019).

Step 1 – occurs during the design and project definition stages, when the prerequisites for deploying CE technical cycles are determined. The return arrow emphasizes the need of a feedback loop from equipment EOL, to design PSS increasingly more suitable to CE and sustainability goals.

Step 2 –represents the return possibilities from the EOL procedures back to the production line, through raw material (recycle), repair and reuse of materials and components, happens during the manufacturing itself.

Step 3 – corresponds to the extra inputs that should happen within the distribution and logistics processes, mainly to cope with sharing, dematerializing and intensification of the use aspects from CE, once the EOL procedures take part (each contract type has different specificities that may require more or less of this step activities).

Step 4 – represents an inner loop of the manufacturing process that can better fit CE technical cycles by reducing, recycling, reusing and repairing components and materials in the production line itself.

Step 5 - represents an inner loop within the use and maintenance group of processes (in this framework example, it was summarized into supply and operation processes group, representing the product and the service aspects of the PSS), which can better fit CE technical cycles by reducing, recycling, reusing and repairing components and materials in the operational phase.

Step 6 – corresponds to the EOL procedures, in which equipment, components, materials may feedback previous steps favouring closed loops business or reach proper environmental disposal. The main goal in step 6 is to reach the “zero” landfill mark.

10.5.3 Contingent effect of stakeholders’ PSS network and Digitalization

Still according to the framework (Figure 2), which may represent either the Brazilian or the UK healthcare environment, the regulatory agencies and federal government policies are fundamental to foster, control and inspect steps 1, 2, 5 and 6. Second-Hand Companies may interfere in steps 2 (limiting the quantity of materials within the manufacturing processes), 5 (offering extra materials and parts for the maintenance phase) and 6 (recollecting obsolete/old equipment from the owners). Healthcare Diagnostics Companies and Hospitals/clinics also interfere in steps 1 (requiring specific design and projects) and 5 (choosing between the different strategies of use and maintenance). Furthermore, Health suppliers may influence steps

4 and 5 (especially in the internal loops of the manufacturer) and Waste Recycling Companies act in steps 4, 5 and 6. In steps 5 and 6, Health Waste Disposal Companies help in the management of the different treatment and destination that should be given to the diversity of materials gathered within the operation and EOL phases. A constant presence, sometimes directly involved in every step, is general consultancy firms that may offer their services either to the PSS provider or to the PSS contractor. They play an important role in making the infrastructure deployment of the most intensive CE projects, mainly focusing on efficiency and performance. Councils Associations (products and professionals representative entities are indirectly participating in public regulatory decisions of every step of the framework. Digitalization is spread all over the PSS lifecycle, but regarding CE opportunities, special attention must be given to step 3, which characterizes UO and RO-PSS, mandatory for distribution and logistics control during the use and users' behaviour monitoring, which is fundamental for the dematerialization and improvement of the business. Digital Companies also take an important role in step 5 fostering reduction and repair from CE technical cycles, through digital monitoring, performance analysis, predictive maintenance through online data and optimization of resources by remotely controlling devices (IoT and analytics). In step 6, traceability of parts and devices in the EoL is already performed by original manufacturers, yet this could play an even more important role in CE, if in a near future, a common open platform could connect regulatory agencies, original manufacturers, third parties maintenance and waste management companies, as a national repository of health devices information. This would facilitate both probable trading business (reuse, refurbish, remanufacture) and proper sanction against irregularities, such as improper maintenance, lack of proper final disposal, over extension of "forbidden materials" lifecycle (belonging to "old devices", as preconized by RhOS, WEEE and further.

10.6 Conclusion

This paper contributes to the literature in three ways. First, it allows identifying the PSS business in healthcare contribution to CE technical cycles aspects, by presenting empirical evidence from sixteen case studies, eight in the Brazilian healthcare sector and eight in the UK. Noteworthy to emphasize the purposeful similarity of organization profiles in both countries. Second, the study identifies the driven forces towards CE: company-driven pathway and the regulation- driven pathway. Third, it shows the contingent effect of the stakeholders in the PSS network and of digitalization.

Findings from the research suggest that the dynamic of the government regulation agency promotes the development of different CE trajectories. Namely, in the UK, the CE trajectory, especially regarding EOL, is fostered by regulatory policies indeed practiced by the providers. In Brazil, the regulation prohibits certain practices, such as second-hand equipment trading, or discourages further refurbishing or remanufacturing activities due to the high complexity of regulation that hinders the CE technical cycles (reuse and remanufacture). The latter confirms the effect of lack of policies related to preserving or creating a circular economy in developing countries (DIAZ, 2017). However, in both countries, the sector is improving towards sustainability; nevertheless, different drivers stimulate activities development and policy makers are fairly far from orchestrating the stakeholders' network through regulation.

In terms of managerial implications, our research shows that the drivers that move companies towards CE, in fact, they do not have sustainability as a main goal, but as a secondary benefit. Nevertheless, environmentally, those CE actions promote the reduction of inputs use, and collaborate in closing the loop with raw materials and energy. Socially and economically, besides generating many parallel jobs and influencing the care for many health patients, they are responsible for making many businesses feasible in the healthcare sector.

This research also has strong implications for public policy in creating and nurturing an environment that supports CE technical cycles through PSS development. Besides, the findings reveal that, in the Brazilian healthcare, conflicts of interests are one of the greatest barriers. They influence the regulation delay towards equipment life cycle extension, for example, by prohibiting the sale of a used equipment, unless fully reviewed by the main manufacturer, which ends up by making the trade costs unfeasible. Therefore, most of the second-hand health equipment market challenges the regulatory system, since poor regulation control makes it viable and attractive for providers and customers. In fact, there is an extra impulse for creating and identifying new business opportunities, regardless of the risks, once economic barriers (financial attractiveness) impose innovative solutions.

Thus, future investigations are needed to work on the role of policymakers to regulate healthcare configuration fostering CE technical cycles. Incentives or penalties proportional to the levels of "CE friendship" may also be further discussed and developed. For future studies, other industrial sectors should be analysed, to broaden the understanding of the relevant contextual specificities. Since this research focused on large providers and large customers within the healthcare sector, the role of technological platforms, and digitalization anchored with the equipment traceability to enable CE technical cycles, is a complementary research niche that can positively influence different innovative stakeholders dynamics. The role of these different players needed to configure these solutions should also be further investigated.

There are some limitations to this study regarding generalization, since the cases were performed in a specific sector, the Brazilian and UK healthcare sector and for that reason, the research results need to be interpreted in the light of this specific context. Additionally, the researchers' and the interviewees' bias must be mentioned since it might influence the results in qualitative approaches. However, this work brings real aspects from a complex sector that can provide insights for both academy and managers.

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