Master's Degree Thesis

Sustainable Product-Service System Design from a strategic sustainable development perspective

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Abstract
Although they lead to several potential sustainability benefits, product-service systems are not intrinsically sustainable. Therefore, this thesis investigates the factors designers should consider in order to ensure sustainable results. A systematic literature review on product-service system and sustainability is combined with three interviews with product-service system providers. The results are analysed through the application of the Framework for Strategic Sustainable Development. The results of the systematic literature review show that there is no unified definition of sustainable product-service system and multiple approaches to address sustainability in product-service system design. By adopting the Framework for Strategic Sustainable Development, a definition of sustainable product-service system and a list of design criteria are developed. This thesis suggests which overarching aspects product-service system designers should consider to integrate a strategic sustainability perspective. The outcome of this thesis supports designers in understanding what a sustainable product-service system could be and what elements it should embed. By combining the definition and the list of criteria, designers can apply a systematic and strategic approach to integrate sustainability in product-service system offerings.

Keywords: Product-service system (PSS); Sustainability; Framework for the Strategic Sustainable Development (FSSD); Systematic Literature Review; Sustainability criteria

Statement of Contribution

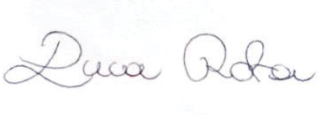
The interest in product-service systems and the conviction that PSS is a suitable business model which leads businesses to become sustainable brought us as a group together. The initial purpose behind this thesis work was to deliver useful insights or even a tool that can help researchers and practitioners to understand and tangibly address sustainability within PSS.

We had a good balance between group work and individual work. We had regularly meetings where we updated each other, discussed about the next steps and divided the tasks. Overall, we were a diverse team, coming from different cultures and with different academic backgrounds. This diversity allowed us to combine our strengths and to investigate the same topic adopting multiple perspectives. Discussions in the research process within the group helped to minimize biased data collecting and bias within the analysis of the result. The whole thesis process was an experience of learning from each other and finding a way of working as a diverse team with different backgrounds together. We all worked on the systematic literature review which was a highly complex process and required a lot of effort from us as a team.

Luca has a background in Management Engineering. He has a pragmatic way of structuring information which is influenced by his Engineering background. His analytical way of thinking and structuring information enabled him to develop the matrix for our analysis of the results. Furthermore, he was actively creating space for discussions and developing new ideas. Many ideas are built on initial thoughts from him. He took a leading role in the development of the overall direction of the thesis. His engaging attitude and his strong but sincere pushing kept us as a team going forwards in our whole thesis process.

Adrian has a background in Mechanical Engineering. He has the ability to find the right information that were needed for the research. Especially during the process of the systematic literature review he did a lot of research. He was always the calm haven in terms of group dynamics and supported the group in finding the shared mental model that was needed in order to continue the work.

Svenja has a background in Business and Management. Her critical reflections on ideas and her critical thinking helped to find the overall research direction and ensured that the group was on the right track by moving forwards. During discussions she was a good counterpart for Luca to confer some creative friction. She took main responsibility in scheduling the interviews with the companies, conducting the interviews and the transcriptions. Regarding group dynamics, her sensibility and her kind attitude ensured to keep a balance regarding group dynamics.



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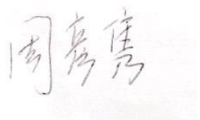

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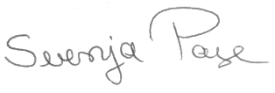

Svenja Paege

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First and foremost, we would like to thank our first advisor Matilda (Watz). She has always been available, carefully following the whole process that led to the realization of this thesis. Through her knowledge and expertise in the research field she has contributing pro-actively to the outcome of this work. Her support and critical reflections were essential for finalizing this thesis. Despite the many challenges we have faced, she has always been a great motivator, bringing out the best in us. We feel so grateful to have had her as our first advisor, the best advisor ever.

Secondly, we thank all the interviewee who freely dedicated us their time. The work that they are doing inspired us and gives hope that businesses more and more see sustainability as important factor to be integrated in practice. Without their knowledge, this thesis would have not been as valuable as it is.

We would also like to thank Yannick (Wassmer) our second advisor who, in spite of the other multiple theses he was supporting, he has always found the time to support us. His suggestions for how we could improve our work as a team together helped us to identify the individual strengths for each team member and how we could integrate them as best as possible in our whole thesis process.

We would also like to thank Merlina (Missimer) for her helpful insights on the use of the FSSD. Her feedback gave us confidence in how we approached our analysis and final results.
We are also grateful of the expertise and support of Marco Bertoni on the topic of PSS. He laid the foundation for this thesis and contributed through valuable feedback and guidance.
Furthermore, we want to thank Karl-Henrik Robèrt for the precious feedback which oriented this thesis as well.

A big thank goes also to the MSLS staff and our MSLS classmates. Being part of this master's program is like being part of a big family. The support, learnings and many new bonds with amazing people general throughout the year will accompany us for the rest of our lives. We will never forget how supportive every one of them was throughout the whole thesis process. Amongst all we would like to mention Arne, Chrissy and Arturo who provided us with helpful feedback. Besides them, we would like to thank Dan, Viliana, Anna, Akash and Hrishabh who freely dedicated their time to helped us and gave some final feedback which was very helpful for finalizing this thesis.

Executive Summary

This thesis explores how sustainability should be addressed when developing sustainable product-service systems from a strategic sustainable development perspective.

Introduction and theoretical background

Humankind is facing environmental and social sustainability challenges, such as water scarcity, resources overexploitation, poverty, war and so on. These sustainability challenges are undermining the capacity of the socio-ecological system to support human life on the planet (Robèrt et al. 2018). This context calls for a transition to a more sustainable society, able to meet its needs without compromising the ability of future generations to meet their own needs (Brundtland 1987; Broman and Robèrt 2017). However, sustainability challenges are interconnected, influencing each other and are difficult to overcome (Williams et al. 2017). Furthermore, the current economic system contributes in many ways to these challenges. Linear business models based on a take-make-waste approach lead to a massive extraction of materials from natural resources, extensive use of materials, water and energy during production and overconsumption from consumers (Willard 2012). Product-service system (PSS) is an academically recognized alternative business model that is able not only to enhance competitiveness, but also to contribute positively to sustainable development (Tukker and Tischner 2006, Vezzoli et al. 2015). Despite the fact that PSS is often seen as a sustainability solution, the development of PSS is not intrinsically sustainable. In fact, there are also cases in which PSS causes higher environmental impacts than a traditional production system (Tukker and Tischner 2006; Vezzoli et al. 2014; Ceschin 2014; Barquet et al. 2016;). Therefore, sustainability needs to be addressed for the development of sustainable PSS in a strategic way (Pigosso et al. 2010).

This thesis was based on the Framework for Strategic Sustainable Development (FSSD). The FSSD is a science-based conceptual framework which offers a definition of sustainability through eight sustainability principles. These principles act as boundary conditions within organizations strategically outlining sustainable scenarios of success (Robèrt et al. 2018). The FSSD was selected because it addresses sustainability systematically and strategically, thus conferring to its user a strategic sustainable development perspective.

This research aims to develop a definition and a set of criteria that could support designers in developing sustainable PSS. For this reason, the primary research question for this thesis is: *What are the factors that need to be considered by a PSS design team to create a sustainable PSS solution?* Since it addresses different topics, the research question was broken up into two secondary research questions: *What is the definition of a sustainable PSS that integrates a strategic sustainable development perspective?* and *What are the critical elements firms need to consider in the design of a PSS to comply with this definition?*

Research Design

This study was based on a two-stage research design. A systematic literature review was identified as suitable method for collecting the data needed. With the gathered data, it was possible to describe the current state of the research regarding the definitions of sustainable PSS. Furthermore, criteria that are considered in the academic field to develop a sustainable PSS were identified. Starting from a list of 516 articles, 24 articles were selected through a double screening process.
At the same time, this thesis attempts to integrate the perspective of companies which offer a PSS. In order to obtain insights into how sustainability is approached in PSS design, and which factors companies consider, semi-structured interviews were conducted.
For analysing both the current research and insights from the interviews, a combination of structured and open coding was adopted. For the structured coding an analysis-matrix was developed based on the systems view of sustainability offered by the Framework for Strategic Sustainable Development (FSSD). Besides the structured coding, an open coding approach was conducted in the analysis of the interviews in order to identify patterns characterizing the business perspective.

Results

As a result of the performed systematic literature review, no unified definition of sustainable PSS emerged. 15 diverse definitions of sustainable PSS and 18 different sets of criteria outlining the concept of sustainability for PSS were identified. The criteria were clustered for sustainability dimensions, generating four categories of criteria: environmental, social, economic and additional. From the interviews, three supplementary definitions and three supplementary sets of criteria were found.

Results analysis and discussion

The definitions and criteria were analysed through the application of the FSSD. Further, the definitions were assessed from systems perspective to see how they address the concept of sustainable PSS. Then the criteria were filtered and clustered, adopting the eight sustainability principles as categories. Finally, the criteria that resulted from the interviews were integrated. As an outcome, a new definition of sustainable PSS, which integrates a strategic sustainable development perspective, was developed. A sustainable PSS is defined as *a PSS designed within robust sustainability constraints providing benefits to stakeholders during its entire life-cycle.* The key features of a sustainable PSS on which the definition was built are: being aligned with the eight sustainability principles, being economically beneficial, integrating a stakeholders' perspective and considering the entire life-cycle. For the development of the definition, only those definitions conferring a holistic perspective to the concept of sustainable PSS were used. Afterwards, a list of 20 environmental and 21 social design criteria is proposed. The list of criteria addresses all those aspects impacting sustainability which designers should consider when developing a sustainable PSS.

Conclusion

By combining the definition and the list of criteria, designers can apply a systematic and strategic approach to integrate sustainability in PSS offerings. The suggested definition provides designers with a systems perspective on sustainable PSS, putting emphasis on its interconnectedness within the socio-ecological system. With the criteria, practitioners have an overview on which factors they need to consider for developing a PSS that is within the eight sustainability principles. Opportunities for additional researches are also reported.

Glossary

Backcasting: A planning method adopted in complex systems which starts with a vision of success. Based on the vision of success, strategic step-by-step actions are planned towards that vision (Robèrt et al. 2018).

Five-Level Model (5LM): A conceptual framework which is designed for having a shared language when planning, acting and decision-making in a complex system. The framework consists of five interrelated levels: system level, success level, strategic guidelines level, actions and tools level (Robèrt et al. 2018).

Framework for Strategic Sustainable Development (FSSD): An overarching framework proposing a unifying and operational definition of sustainability, and a systematic approach to fulfil it (Bröman and Robèrt 2017). It is based on the application of the Five-level Model to sustainable development (Robèrt et al. 2018).

Funnel Metaphor: An approach to visualize through the closing walls of a funnel, the degradation of the socio-ecological system by society's current unsustainable practices (Robèrt et al. 2018).

Holistic: The term holistic is used for describing approaches or actions that are concerned on the wholeness of a system rather than its individual parts (Cambridge Dictionary n.d.).

Linear business model: a business that transforms inputs into finished products or services and sells those to the consumer. It is a business model based on a linear supply chain (Johnson 2017).

Products: "Anything that can be offered to a market for acquisition, use or consumption that could satisfy a need or want" (Claessens 2015).

Product-Service System (PSS): A combination of tangible products and intangible services which aims to meet specific customer needs (Tukker 2004).

Service: "A special form of product which consists of activities, benefits or satisfactions offered for sale that are intangible and do not result in the ownership of anything" (Claessens 2015).

Social life-cycle assessment: "It's a method that aims facilitating companies to conduct business in a socially responsible manner by providing information about the potential social impacts on people caused by the activities in the life-cycle of their product" (Dreyer, Hauschild, and Schierbeck 2006).

Socio-ecological system: A combined system formed by the complex interactions between biosphere and society (Robèrt et al. 2018).

Stakeholders: A person, group or organization that has an interest or concern into an organization. Stakeholders can either be affect by or have an impact on organization's actions, objectives and policies (Landau 2017; BusinessDictionary, n.d.).

Strategic Sustainable Development (SSD): The term Strategic Sustainable Development derives from the FSSD. Sustainable Development becomes Strategic when it is planned foreseeing and preventing unexpected consequences on the socio-ecological system (Bröman and Robèrt 2017). The SSD is based on the understanding of the sustainability challenges and scientific approaches to help society strategically approach the sustainability with integrating a systems perspective (Robèrt et al. 2018).

Sustainability challenge: "The combination of the systematic errors of societal design that are driving humans' unsustainable effects on the socio-ecological system and the serious obstacles to fixing those errors" (Robèrt et al. 2018).

Sustainable development: According to Brundtland's statement (1987), "Sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

Sustainability Principles (SPs): The sustainability principles are scientific-based basic conditions society must comply with to preserve the socio-ecological system (Robèrt et al. 2018).

Sustainability Sub-optimization: Unsustainable unintended consequences that derive from actions lacking system perspective (Byggeth and Hochschorner 2006; Dijkman, Rödger, and Bey 2015).

Systems Perspective/ thinking: A holistic approach to deal with complex systems which allows detect the single elements of a system and think of how they interact with each other as a whole (Robèrt et al. 2018).

Triple-Bottom-Line (TBL): "It is a framework that incorporates three dimensions of performance: social, environmental and financial. The TBL dimensions are also commonly called the three Ps: people, planet and profits" (Slaper and Hall 2011).

Value Creation: "The performance of actions that increase the worth of goods, services or even a business" (BusinessDictionary, n.d.).

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List of Abbreviations

8SPs	Eight Sustainability Principles
PSS	Product-Service Systems
FSSD	Framework for Strategic Sustainable Development
5LM	Five-Level Model
RQ	Research Question
SLR	Systematic Literature Review
SP	Sustainability Principle
SSD	Strategic Sustainable Development

List of Figures and Tables

1. Introduction and Theoretical Background

The current economic system is in many different ways contributing to sustainability challenges like resource scarcity, environmental pollution, overconsumption, poverty and inequality. To transform the economic system, and encourage a sustainable development, new business models are needed.

1.1 Sustainability Challenges

Humanity is facing sustainability challenges. The exponentially increasing degradation of the ecological system is growing the risk of tipping the biosphere into a state where it will no longer be able to support human life (Willard 2012; Steffen et al. 2015). At the same time, society is facing social sustainability challenges. Amongst them more than one billion people are still living under the poverty line, and income inequality is increasing within many countries across the world (World Economic and Social Survey 2013). According to Keeley (2015) in the 1980's, the income of the wealthiest ten percent was on average seven times higher than the income of the poorest ten percent. Today, more than 30 years later, it is nine and a half times higher.
For understanding and visualizing the gravity of the sustainability challenges that humankind is facing, the funnel metaphor (displayed in Figure 1) could be used. On the one side, natural resources and ecosystem services that support human life are decreasing. On the other hand, the human population and the consumption of resources and materials are increasing. Those two general trends combined lead to growing pressures on society regarding environmental, social and economic issues. (Broman and Robèrt 2017, p. 21).

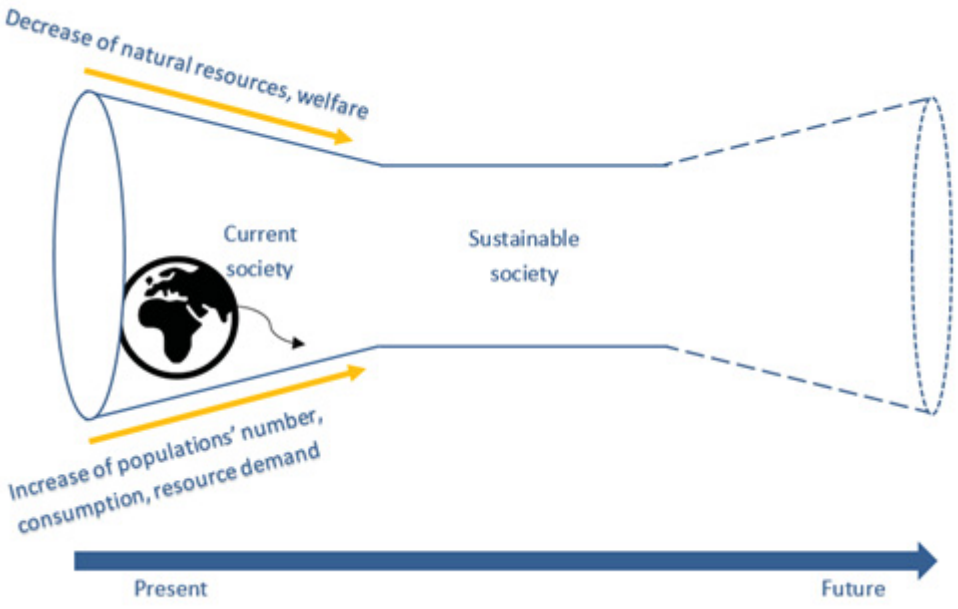


Figure 1: The Funnel metaphor (adopted from Robèrt et al. 2018)

The narrowing wall of the funnel is visualizing the boundaries for the secure space for humankind and represents the progressively degrading socio-ecological system. As described

by Robèrt et al. (2018), the existing capacities of both the planet and society to sustain civilization are systematically degrading due to the unsustainable practices of our society.
Linear business models (also known as the take-make-waste business model), that most companies have adopted today, are one of the main drivers of the sustainability challenges (Willard 2012; Ceschin 2014). Being based on systematic overconsumption of natural resources, these business models lead to the degradation of the biosphere through (Willard 2012):

1. the systematic increase in concentration of substances from the Earth crust, such as heavy metals and fossil fuels;
2. the systematic degradation of the biosphere through physical means, such as deforestation and over-harvesting;
3. the systematic generation of waste produced by society, like chemicals and dioxins.

Simultaneously, linear business models cause negative impacts also on the society, as they contribute to abuses of political and economic power preventing the satisfaction of basic human needs such as clean air, potable water, nutritious food and quality of life (Willard 2012).

Being sustainable is critical and will become even more critical for businesses and organizations to survive over time (Robèrt et al. 2018). In particular for businesses, being unsustainable may generate e.g. costs due to adapting to new environmental policies and legislation. In order to cope with the environmental and social sustainability challenges, countries all over the world are establishing strict regulations for businesses (Chierici and Copani 2016) and promoting mindful and transparent practices in businesses by introducing reporting on sustainability (Fernandez-Feijoo, Romero, and Ruiz 2014, p. 54). Furthermore, companies which continue their unsustainable practices might be affected by increasing financial impacts through higher and even unpredictable costs for scarce natural resources (França et al. 2017).
Being unsustainable as business can also cause risks of losing customers or market shares to competitors who adopt more sustainable practices (França et al. 2017; Robèrt et al. 2018). The market demand for sustainable products and services is also increasing (Lin, Tan, and Geng 2013, p. 102). On the other side, integrating sustainability may also mean to drive innovation opportunities and possibilities for gaining market shares (Willard 2012; Broman and Robèrt 2017). In other words, unsustainable activities may generate in the long-term severe concerns for companies to survive on the market. Therefore, businesses need to integrate strategically sustainability into their purposes and practices.

The sustainability challenges are complex: social and ecological aspects are interconnected in a complex way (Robèrt et al 2017). Sustainability issues, consequently, can only be solved by focusing on the root of the problem, inducing a need for a radical transformation (Missimer 2015). In other words, for a full transition towards sustainability, a radical change in the way current society produces, consumes and lives is required (Vezzoli 2017). Therefore, there is a need to transition from the current state to a sustainable society that is able to satisfy the present needs without compromising the ability of future generations to meet theirs (Brundtland 1987). Given the complexity of the sustainability challenges, businesses must adopt an overarching transformative change. This kind of transition is defined as Sustainable Development (Robèrt et al. 2018). Given the critical role that companies and organizations play in our society and their contributions to the sustainability problems, they can take a lead in the transition to a sustainable society (Willard 2012). Hence, it is imperative to radically change the current linear business models, to protect the ecosystem, improve the efficient use of resources, narrow the wealth gap and reduce social inequality. Therefore, manufacturers and service providers must

shift from the linear business models to business models that have more potential to be sustainable (Willard 2012). Thus, reflecting not only on the production processes but also thinking about the consumption, people's lifestyles and their access to goods and services. To develop appropriate solutions that addresses the complexity of the sustainability challenges in a systematic way, businesses must adopt a strategic approach (Baumgartner and Korhonen 2010). Strategic sustainable development becomes therefore a critical approach to move businesses towards a sustainable future.

1.2 Product Service Systems and Sustainability

Product-services system (PSS) is recognized as an alternative business model that not only enhances competitiveness but also has the potential to contribute to sustainable development by addressing production processes, the provision of products and services and redesign consumption behaviour (Tukker and Tischner 2006; Vezzoli et al. 2015).
A Product-service system can be described as "the result of an innovation strategy, shifting the business focus from designing and selling physical products only, to selling a system of products and services which are jointly capable of fulfilling specific client demands" (Manzini and Vezzoli 2002, p. 4). Tukker and Tischner (2006) distinguish between three categories of PSS: (1) product-oriented, (2) use-oriented and (3) result-oriented. According to Baines et al. (2007), in a product-oriented PSS, the ownership of a product is at the side of the customer and the related services, which include the installation, maintenance, repair, upgrading and recycling of the product as well as the consultancy and training for using the product, are provided by the PSS provider. Regarding the use-oriented PSS, the ownership of the product belongs to the PSS provider and the customer needs to pay for the service of using this product. The last and third category of PSS, the result-oriented PSS, can be described as a tool to reach a specific desired outcome. This is enabled through an agreed function of the PSS between the provider and the customer.
Although PSS emerged as a sustainable solution, the development of PSS is not intrinsically sustainable and there are cases in which PSS causes higher negative environmental impacts than a traditional business model (Tukker and Tischner 2006; Vezzoli et al. 2014; Ceschin 2014; Barquet et al. 2016;). PSS can require high levels of transport intensity, which is not compensated by the other environmental advantages (Ellger and Scheiner 1997; Graedel 1997). Examples come from the food industry: convenience meals produced in centres for preparation and then transported in cooling chains can provide high value for the customers increasing its quality of life, but there is a negative impact on energy consumption (Tukker and Tischner 2006). Another example is connected to chemical management services (CMS). In order to extend the life-cycle of their offerings, PSS can introduce chemicals which are more resistant and long-lasting but also more toxic (Tukker and Tischner 2006).

PSS can positively address economic, environmental and social benefits. From an economic point of view, PSS has the potential to generate multiple advantages. Tukker and Tischner (2006) suggest three advantages with PSS. First, PSS is tailored for the customer needs, and therefore, it leads to a higher level of customer loyalty, strengthening and extending the relationship between customers and businesses. Secondly, this long-term relationship improves innovation, as PSS-provider and clients can co-create solutions that can address current needs or problems by developing alternative or new solutions compared to the traditional product offering. Also, compared with standard product-manufacturing, PSS potentially improves the strategic position of the firm in the value chain, by integrating activities which are closer to the

customer and have higher profit margins. Based on different research studies, Ceschin (2014) points out that businesses which offer a product-service system can generate competitive advantages on the market.
Along with economic advantages, PSS potentially leads to both environmental and social benefits. On the customer side, the costs related to the acquisition, use, maintenance and product replacement can potentially lower (Manzini and Vezzoli 2002). Whereas the service provider is stimulated to use and maintain better the equipment increasing both its efficiency and effectiveness (Pigosso et al. 2010). Therefore, PSS may require less material and energy in the development phase in comparison to the standard product offerings. Furthermore, when the PSS is use-oriented, PSS providers are responsible for the whole life-cycle encouraging the re-use of the product at the end of its life ensuring less waste (Manzini and Vezzoli 2002; Tukker and Tischner 2006). Moreover, PSS encourages the adoption of a leaner production approach (Tukker and Tischner 2006), avoiding over-production and reducing the need for warehouses, avoiding their environmental impacts. Hence, PSS has the potential to play a critical role in tackling overconsumption as it can lead the transition from product ownership to service-based products, by directly impacting customer behaviours from single-use product consumption towards shared economy (Sora et al. 2012).
PSS offers social benefits by offering new job roles for PSS implementation leading to opportunities for employment and by increasing the quality of life and the well-being of customers (Manzini and Vezzoli 2002; Tukker and Tischner 2006). As PSS models sell access rather than mere product ownership, they could lead to increased accessibility to groups with lower purchase power, as a lower cost per use replaces a higher full product purchase cost (Vezzoli et al. 2018). Therefore, use- and result-oriented PSS represents an opportunity "to respond more easily to unsatisfied social demands with lower overall costs" (Manzini and Vezzoli 2002).
As highlighted above, PSS has the potential to generate economic, environmental and social benefits for both developers and users leading the society in the direction of sustainability, but this potential must be addressed strategically (Pigosso et al. 2010). Ensuring that the benefits are achieved simultaneously in the environmental, social and economic dimension for the whole PSS lifecycle the integration of sustainability in the design is critical (Pigosso et al. 2010). In fact, the design determines the whole life-cycle of the product and its relative impacts on both the environment and society (Waage 2007). Therefore, the design process is one of the most influential factors when developing sustainable PSS since the impacts or effects are more significant as sooner sustainability is considered in the development (Sousa-Zomer and Cauchick-Miguel 2017).
However, as reported by the analysis of Pieroni et al. (2017), only a minority of PSS design frameworks include activities, methods or tools supporting the development of PSS while integrating both the environmental and the social dimensions of sustainability strategically. Even though there are already criteria assessing the sustainability of PSS into the design, most of them are focused on the dimension of environmental sustainability, e.g. eco-design principles (Pigosso et al. 2010; Sora et al. 2012). Therefore, there is a need for a comprehensive framework able to address the sustainability potential of PSS in the design from a systems perspective.

1.3 Framework for Strategic Sustainable Development

Leading the transition towards a more sustainable society is a complex task that requires collaboration amongst experts across multiple sectors and disciplines (Broman and Robèrt 2017). For this reason, Broman and Robert (2017), aimed to establish a shared language and a

systematic approach in dealing with sustainability. This involved developing what is known as the Framework for the Strategic Sustainable Development, (FSSD) (Broman and Robèrt 2017). Due to its potential in addressing sustainability and in conferring a Strategic Sustainable Development perspective to its users, the following thesis was based on the FSSD. FSSD is a scientifically recognized framework specifically developed to consider the complexity of sustainability, through adopting a systems perspective (Broman and Robèrt 2017). The FSSD can help organizations to understand the sustainability challenge and the related opportunities and benefits of proactivity. Furthermore, it supports organizations to incorporate a systems perspective and supports planning towards sustainability, e.g. through informing decision-making by assessing potential practices. For increasing the effectiveness of complementary tools and methods for strategic sustainable development, the FSSD offers guidance in selecting, developing and combining those tools and methods (Robèrt et al. 2017). The FSSD adapts the Five-Level Model, a model which supports planning and acting in complex systems, and integrates a sustainability development planning approach (Robèrt et al 2018).

The Five-Level-Model

Transitioning to a sustainable society is a difficult task, which requires many disciplines and sectors to collaborate. The question is, how it can be possible to convene these various sectors to achieve this objective. The Five-Level Model (5LM) is a framework which offers a structure for information in a way that makes it useful for planning in a complex system based on system thinking. Furthermore, it can be used to analyse any complex system, and it is designed for problem analysis, decision-making, planning for investment programs, as well as supporting the development of strategic action plans. This model helps to assess information through five categorical levels. The system level of the 5LM is where the planner places all information about a given system. The success level defines the overall goal that needs to be achieved in order to have a successful planning process. The strategic guidelines level is about choosing concrete actions as part of an overall strategic plan to accomplish the goal. The actions level describes concrete actions that are chosen to move towards the success defined on the success level based on the overall strategic guidelines. The tools level supports the planning and implementation to reach the vision of success. (Robèrt et al. 2010, p. 25-29). By applying the SSD perspective into the 5LM it refers as the Framework of Strategic Sustainability Development (Robèrt et al. 2010, p. 34). Therefore, the FSSD provides a platform which responses to the vagueness and uncertainty in planning towards sustainability, and provides a common language and understanding, to facilitate people towards sustainability (Broman and Robèrt 2017).

Figure 2 gives an overview of each level of the 5LM and how they become the FSSD through the application of an SSD perspective. After the figure, each level of the FSSD is explained further.

The Five-Level Model with Explanations	Integration of SSD perspective	The Framework for Strategic Sustainable Development
System: The system that is relevant to the overall goal/ success.	System level	The global socio-ecological system (society within the biosphere); An overview of the sustainability challenge.
Success: The definition of success.	Success level	A sustainable society (one that complies with the Sustainability principles).
Strategic guideline: The strategic guideline used to select actions that move towards success in the system.	Strategic guideline level	Backcasting from success; A decision structure that enables strategic prioritization.
Actions: The concrete actions that follow the overall strategic guidelines to reach success.	Action level	The concrete actions that are implemented to move towards a sustainable society (success).
Tools: The tools that support the planning.	Tools level	The tools that support efforts to reach sustainable society (success).

Figure 2: The Five-Level Model & The Framework for Strategic Sustainable Development (FSSD) (Robèrt et al. 2018)

System Level

One of the key features in the system level of FSSD is the global socio-ecological system. "The global socio-ecological system is the biosphere and society interacting in a complex way to form a combined system" (Robèrt et al. 2010). The triple-nested-systems model illustrates the three pillars of sustainability: environmental, social, economic (Figure 3). Noticeably, the economic system is a subsystem and is nested in the larger social and environmental system, while it is entirely dependent on the continuation of these two systems. In other words, companies are unable to exist on its own. Companies and society depend entirely on the availability of natural resources. Sufficient food, clean and fresh water are essential for human beings' existence. Similarly, companies also require the resources from nature to continue their daily operations. This indicates a strong dependency of the economic system on the environmental and societal system which makes it clear that companies cannot survive segmented from what is known as the socio-ecological system (Willard 2010; Robèrt et al. 2018).

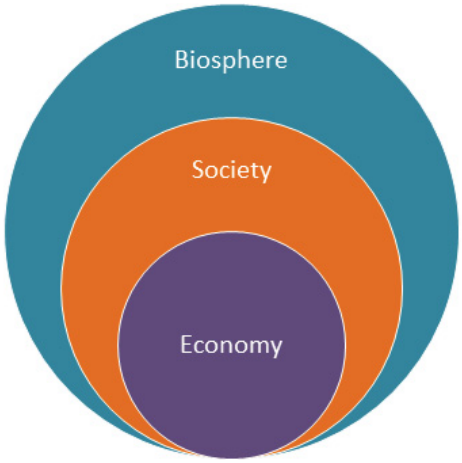


Figure 3: Triple-nested systems model (adopted from Willard 2010)

Success Level

The FSSD offers a definition of sustainability through the adoption of eight sustainability principles, criteria that act as system boundaries for both the ecological and social dimensions in a theoretically sustainable scenario (Robert et al. 2018). By having a vision within those boundaries, sustainable development can be achieved (Missimer 2015).

The eight sustainability principles consist of three ecological principles and five social principles (table 2). Regarding the ecological SPs, the term "systematically increasing" is used and refers to the systematic degradation of the biosphere. The three ecological principles represent three basic mechanism how society is harming the biosphere by either increasing the concentration of natural and synthetic waste or degrading the nature by physical means (Robèrt et al. 2018). The concept of "structural obstacles" is often associated with the social sustainability principles. This concept refers to social constructions within society regarding political, economic and cultural factors that are difficult to overcome or avoid by the people that are affected by them. Structural obstacles are an accumulated amount of activities of social unsustainable behaviour which leads to a deeply rooted negative impact on society. Therefore, the usage of the term "structural obstacles" is essential when defining the social sustainability principles (Missimer 2015).

Table 1: Sustainability Principles (Robèrt et al. 2018)

Sustainability Principle	Explanation
SP1	The amount of substances from the earth's crust aren't introduced in a way which leads to a systematic increase of the concentration of these substances. An example of those kinds of substances would be crude oil from the lithosphere.
SP2	Substances produced by society such as chemicals like Nitrogen oxides are used in a way through societal activities that don't lead to a systematic increase of these kinds of substances in the biosphere.
SP3	The biosphere is not systematically degraded by physical means. Examples for activities that would be a misalignment with this principle are overfishing overharvesting of forests.
SP4	People are not subject to structural obstacles to health. This means that people are not exposed to social conditions that systematically undermine their possibilities to avoid injury and illness either physically, mentally or emotionally (e.g. dangerous working conditions or insufficient wages).
SP5	People are not subject to structural obstacles to influence. This means that people are not systematically hindered from participating in shaping the social systems they are part of (e.g., by suppression of free speech or neglect of opinions).
SP6	People are not subject to structural obstacles to competence. This means that people are not systematically hindered from learning and developing competence individually and together (e.g. by obstacles for education or insufficient possibilities for personal development)
SP7	People are not subject to structural obstacles to impartiality. This means that people are not systematically exposed to partial treatment (e.g. by discrimination or unfair selection to job positions).
SP8	People are not subject to structural obstacles of meaning-making. This means that people are not systematically hindered from creating individual meaning and co-creating common meaning (e.g. by suppression of cultural expression or obstacles to co-creation of purposeful conditions).

Strategic Guidelines Level

The strategic guidelines level includes guidelines for identifying the most strategic actions for reaching the vision of success (Broman and Robèrt 2017). These actions are developed through backcasting from principles and selected through a prioritization process (Robèrt et al 2018).

Backcasting from principles is a planning process which defines a vision of success adopting basic principles as constraints and supports to identify the gaps between the current state and the envisioned future. In the FSSD, the eight sustainability principles are adopted as basic principles for backcasting (Robèrt et al. 2018).

In order to achieve the vision of success outlined through backcasting, actions bridging the gaps between the current state and the envisioned future are planned. All actions need to be in

alignment with the 8SPs. The FSSD offers three criteria for prioritizing actions. First, an action should be a flexible platform on which other possible actions can be built on to reach the vision. Second, an action should help to reach the vision as soon as possible. And third, an action should lead to returns on investment for the organisation (Robèrt et al. 2018).

The Actions Level

The actions level gathers all those concrete actions defined in the strategic guidelines level supporting organizations in moving towards their envisioned future (Robèrt et al. 2018).

The Tools Level

The tools level examines all those tools potentially supporting organizations in the application of the FSSD. The tools are chosen in alignment with the system level, the success level, the strategic guidelines level and the actions level (Robèrt et al. 2018).

1.4 Aims, Scope and Research Question

To give more clarity to businesses in how to integrate sustainability into a PSS, a set of guidelines could support PSS practitioners to integrate strategic sustainability in the design. Therefore, a definition of sustainable PSS must first be developed to provide a shared vision to guide practitioners in the development of sustainable PSS and provide awareness of the sustainability impacts through offering a PSS solution. Through reviewing literature, it was discovered that there are multiple definitions of sustainable PSS. Therefore, research would benefit from a common understanding of what a sustainable PSS is, in order to channel the research into a common direction. A definition of sustainable PSS based on the literature, coupled with a strategic sustainable development and a business perspective, would allow the establishment of a foundation for possible strategic guidelines for the design of sustainable PSS. Guidelines could support design teams in systematically integrating sustainability into PSS design. Therefore, this thesis aims to create a shared understanding of sustainability by formulating two aims. The first aim is to propose a definition of sustainable PSS derived from theory and practice, and the second aim is to provide a set of criteria that guides design teams towards complying with this definition. Since the initial aim of this research is to develop a definition of sustainable PSS, the system level from the FSSD is used to assess the definitions of sustainable PSS emerged from the literature. For assessing the criteria for developing a sustainable PSS emerging from literature and practice, the success level of the FSSD is used. As this research is developing a foundation for future developments of guidelines, the strategic guideline, action and tools level are not addressed any further throughout this research.

As PSS is gaining more and more attention as one possible solution in the transition towards sustainability, the target audience of this thesis is both researchers in the field of sustainable PSS or sustainable business models, and practitioners in terms of PSS designers and providers. Given the aims and intended audience, the study is based on a systematic literature review on academic publications and complemented with interviews with industry representatives. The results are analysed with a lens of strategic sustainable development.

The **primary research question** guiding this thesis, is
What factors need to be considered for a PSS design team to create a sustainable PSS solution?
Due to its complexity while addressing different topics, the research question is divided into two secondary questions. Furthermore, the research design is based on the following secondary research questions:
Secondary research Question 1: *"What is the definition of sustainable PSS integrating a strategic sustainable development perspective?"*
Secondary research Question 2: *"Which critical elements may firms need to consider in the design of a PSS to comply with this definition?*

2. Research Design

For answering the research questions presented in the previous section, a qualitative study was designed, which was structured by adopting the model from Maxwell (2013). This model offers a structure with five different areas, which are interconnected. It allowed to design a research process that is iterative and multi-directional rather than linear and inflexible. This allowed the researcher to reflect on the research process and progress consistently while allowing for adaptation to ensure the alignment throughout the four different areas (Figure 4). In order to answer the research question presented in the previous section, the following research methods were selected.

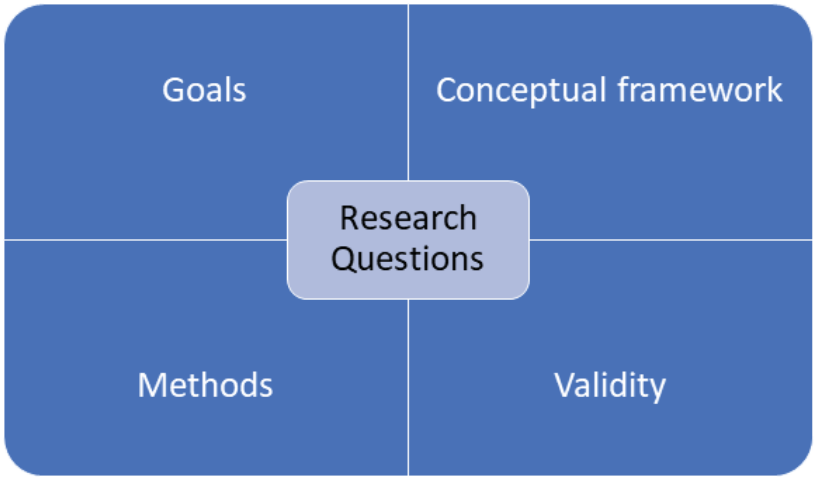


Figure 4: Interactive Design Model for Qualitative Research (adopted from Maxwell 2013)

This study was based on a two-stage research design. This involved an inductive approach known as qualitative research. The aim of this approach was to develop concepts, insights and understandings based on patterns found in the investigated data (Taylor, Bodgan, and DeVault 2016). A systematic literature review was identified as suitable method for collecting data for both describing the current state of research regarding the definitions of sustainable PSS and identifying criteria that are considered in theory to develop a sustainable PSS. At the same time, this thesis attempted to integrate the perspective of practitioners. In order to gain insights into how sustainability is approached in PSS design, and which factors companies consider, semi-structured interviews were conducted. For analysing both the current research and insights from the interviews, a combination of structured and open coding was adopted. The codes for analysing the data are based on a system view of sustainability and were derived from elements of the Five-Level Model of the Framework for Strategic Sustainable Development (FSSD). The description of how the 5LM from the FSSD is applied to this study can be found in section 2.3.1. Furthermore, the description of the analysis matrix can be found in section 2.3.1 and 2.3.2. Each of the steps of the research design of this study is summarized in the following table.

Table 2: Research Design

	Data needed	Method	Outcome	Answer to research Question
Data Collection	State of research about the definition of sustainable PSS	Systematic literature review	State of the Art of definitions for sustainable PSS	Secondary RQ 1
	Criteria considered for developing a sustainable PSS in research		State of the art of criteria for sustainable PSS	Secondary RQ 2
	Economic/ business perspective on how sustainable PSS is defined in practice	Semi-structured Interviews	Insights from practice on sustainable PSS	Secondary RQ 1
	Criteria considered for developing a sustainable PSS in practice		Criteria from practice for developing a sustainable PSS	Secondary RQ 2
Data Analysis (Framework Analysis using FSSD)	Outcome from systematic Literature Review	Structured and open coding (Codes derived from FSSD)	Proposal of definition of sustainable PSS and set of criteria	Primary research question
	Outcome from Interviews			

2.1 Systematic Literature Review

Gough et al. (2017, p. 2) describe a systematic literature review as "a review of existing research using explicit, accountable rigorous research methods'" which enables the researcher to identify all available studies related to a topic of interest. A systematic literature review is considered as secondary data, based on the collection of primary research (Kitchenham 2004). For conducting a consistent systematic review, the process should to comply with specific core principles such as the four described by Booth et al. (2016): transparency, replicability, clarity and auditability.

According to Kitchenham (2004), there are three reasons for conducting a systematic review. A systematic review can summarize existing knowledge in the research gathered so far. By systematically reviewing existing research, it is possible to identify gaps and propose suggestions for future investigation. Additionally, a systematic review can provide a consistent background, giving a solid foundation for new research avenues. Therefore, the above rationales for conducting a systematic literature review can be applied to this research as well. There is rich literature on PSS already, including a range of frameworks and design techniques with several definitions of sustainable PSS, relying on different models for considering and evaluating sustainability (e.g. triple-bottom-line). By carrying out systematic research, this study aims to identify the relevant existing knowledge on the topic, then summarize and analyse it in order to answer the primary research question. The structured and consistent procedure a

systematic review follows reduces the bias of the researchers and ensures that the data are collected in a plausible way (Booth et al. 2016).
Mallet et al. (2012) describe one possible process of conducting a systematic literature review with the following six steps (table 3).

Table 3: Stages of systematic literature review (Mallet et al. 2012)

Stage in the Systematic review	**Description**
1) Define research Question	Constructing a research question which serves as a basis for the search string in the literature search.
2) Develop protocol	Create a protocol that describes search string, search strategy, inclusion and exclusion criteria and an approach for the synthesis.
3) Actual search	Conduct the systematic search: the studies are retrieved from the chosen database(s); all studies found are included at this stage.
4) Screening	Screening of the all retrieved studies, screened regarding the relevance of title, abstract and full text, by using predefined inclusion and exclusion criteria. Consistency is ensured through piloting with all researchers screening the same studies and then comparing the results.
5) Final list of relevant research	Once screening has been completed, the studies that are included in the final analysis.
6) Synthesis	The final stage involves the extraction of relevant quantitative and/or qualitative data in order to synthesize the evidence.

The two secondary research questions framed the systematic literature reviews. A protocol, including a search string and inclusion and exclusion criteria, was developed. Based on preliminary research, key concepts and related terms were developed for creating the string. Boolean operators were adopted for the development of the string: tailoring the string to the topic of this thesis ensured the comprehensiveness of the research (Olson and Allen 2018). The criteria for inclusion and exclusion were based on the research question and the developed key concepts. Then the string was applied in the chosen database. The database used for this systematic literature review is SCOPUS because it is currently the largest peer-reviewed articles database (Elsevier n.d.). Two screening phases were conducted in order to ensure the integration of all relevant articles. The first screening phase consisted of superficial screening of the abstract, introduction, results and a brief skimming over the whole article based on a first set of criteria. The second screening was more detailed with an in-depth investigation if the article would help to answer the secondary research questions. After those two screening phases, a final list of relevant articles emerged and were prepared for the analysis. The final step was a synthesis to present the results from the systematic review.
A detailed explanation of the steps and outcomes of the systematic literature review follows in section 3.1.

2.1.1 Systematic Literature Review Process

The systematic literature review process comprised three phases: the string line development, the first screening and the second screening (figure 5). Each phase is further explained in this chapter.

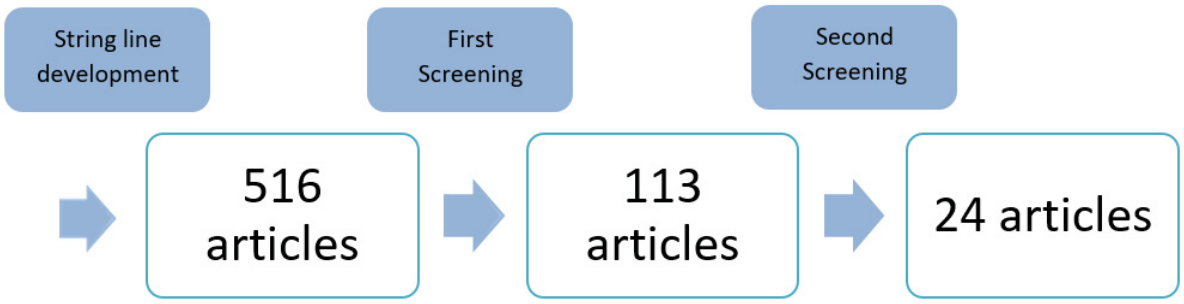


Figure 5: Systematic literature review process

String line development
Key concepts emerged by exploring well-known academic publications in the field of PSS and sustainability. These were categorized into four main categories of concepts. The four categories are "PSS", "sustainability", "design" and a particular category clustering a wider range of words which was named as "other". Thereafter, synonyms and related terms were added based on the concepts. For example, for the category of PSS, terms like "servitization" or "integrated products" were added to the more common "Product Service Systems" and "PSS business model". Regarding the concept of "sustainability", terms like "environmental factor" or "social effect" were gathered in order to ensure that articles related to sustainability without explicitly mentioning it are also covered. In this way, a table of all the key concepts and related terms needed for the development of a robust research string line was systematically created. The concept table can be found in the appendix E.
The resulting string lines were tested in the database SCOPUS. SCOPUS was selected due to its reliability and recognition as the most extensive database for peer-reviewed articles (Elsevier n.d.). Each string line was assessed, firstly, by looking at the number of articles covering in the database. Secondly, it was verified if those strings were covering the five specific articles which emerged from the preliminary literature investigation as the most representative of the research topic.

TITLE-ABS-KEY ((PSS OR "Product-service System" OR "functional product" OR serviti?ation) AND ("Environment* impact*" OR "Social impact*" OR sustainab*) AND (assess* OR evaluat* OR measur* OR definition OR framework)) OR TITLE-ABS-KEY ("Sustainable PSS" OR "sustainable product-service system")

Two queries compose the string line. The first one was developed by targeting those articles focused, on the theme of PSS and sustainability assessment (as allowed by the operator TITLE-ABS-KEY). In detail, this query addresses the articles which mention the topic of PSS also in the forms of "functional product" and "servitization" or "servitisation". Amongst these articles, only those explicity mention sustainability or consider it through the keywords of

environmental and social impact are selected. Finally, the query filters only those articles which include an assessment, a definition or a framework. The second query was structured to include all those articles, not covered by the first query, mentioning explicitly in the title, abstract or in the list of keywords the concept of sustainable PSS. By undergoing the string line into the database, the initial list of articles to be considered for the systematic literature review was generated. As a note, the key concept category regarding the design emerged from the preliminary literature investigation, was excluded from the string line and integrated into the process of selection of the articles as a filtering criterion in the further steps of the literature review instead.

First screening phase

In order to identify the most suitable articles from the literature, two screening phases were conducted. In the first screening phase, all the articles and books found were listed in one shared Excel spreadsheet. Twenty-seven papers were directly excluded because they were conference papers. After that, the most relevant articles were identified based on three key criteria "PSS", "Sustainability" and "Design". An article which considered all three aspects was recognized as more likely to contain the information needed for answering the primary research question. The criteria "PSS" was needed because there were also articles found through the string which contained the acronym PSS as well but were related to medical terminology or PSS for "Product Stewardship Strategy". Therefore, these criteria helped to identify the articles that were related to PSS as a business model. The criteria "Sustainability" was fulfilled when an article discussed PSS in the context of sustainability, e.g. if it mentioned how PSS contributes to sustainability. The criteria "Design" was covered when an article was considered to be an assessment or guidelines for design to a certain degree.

The articles were evenly distributed between the team members. To ensure that the screening was done in the same way by three different individuals, a common assessment process was developed which consisted of the three following steps: reading the summary of the article, reading the introduction and the conclusion of the article and screening the rest of the article. Based on the information identified through this process, it was assessed which of the three criteria was fulfilled by the article. If all three criteria were fulfilled, the article became part of the second screening phase. This process of screening and assessment reduced the number of articles which moved on to the second, more in-depth screening. From 516 initial articles, 113 articles were identified and underwent a second screening.

Second screening phase

The second screening was an in-depth screening. The team read the articles thoroughly and searched for either a definition of sustainable PSS or clear criteria which needed to be fulfilled to have a sustainable PSS. By including both, the articles which contained a definition of sustainable PSS and also the articles that delivered criteria for making a PSS sustainable, data were gathered which answered both secondary research questions. In some articles, the use of a definition of sustainable PSS from another source was recognized. In those cases, the articles were excluded. To ensure that the final list of articles for the analysis was chosen based on a common mindset in the group, group meetings were scheduled to discuss the inclusion and exclusion of articles. Clear rationales were presented on why specific articles were included or excluded in the final list for the analysis. At the end of this step, the final collection of articles was identified and became part in the analysis. The second screening phase reduced the list of articles from 113 to 24 final articles.

2.2 Semi-structured Interviews

As a complementary method to the systematic literature review, semi-structured interviews were conducted to obtain a business perspective on the research topic to answer the main research question. Semi-structured interviews are a mix of prepared questions and unprepared questions which enable the interviewer to be flexible in the conversation and adapt to the interviewee (Austin and Sutton 2014, p. 438).
One benefit of semi-structured interviews is the possibility to tailor the questions in relation to the level of interaction with the interviewee and to the emergence of additional sources of knowledge that were not considered during the preparation of the interviews (Savin-Baden and Howell Major 2013). Having a standard protocol of questions that were prepared beforehand, enabled the research group to touch on all the topics of the investigated interests to ensure that data were gathered in order to answer the sub-research questions and the collected information were complete and consistent. As information is collected through a conversation with the interviewee, it helped to get an understanding of the investigated topic (Harell and Bradley 2009). The prepared questions of the interview can be found in the appendix F.
These interviews were structured with the aim to understand how companies approach PSS and sustainability together in the development of those system solutions. Furthermore, the intention was to identify specific criteria adopted by those companies to address and evaluate sustainability in the early design or development stage of their PSS offering. Primary data collected through interviews was needed due to the lack of such data in existing researches investigating if companies see a difference in PSS and a sustainable PSS and how they approach this difference. Furthermore, this study wants to create a shared understanding of sustainable PSS in research and practice. The interviews were needed to gain this understanding from the practice of sustainable PSS, which is needed to answer the primary research question. Therefore, only representatives from businesses who were committed to sustainability were interviewed. This means the research group talked to people aware of the topic thus ensuring valuable findings for the research question. Also, by gathering knowledge from practitioners, this research ensured to include a business perspective on the topic of sustainable PSS. In approaching businesses, the research team did not provide in advance a definition of sustainable PSS and did not introduce the concepts of FSSD to them. That approach was adopted to minimize risk of bias and thus to maximize the reliability and validity of collected data from the different practitioners interviewed.
The interviews were carried out with representatives of three different companies which offer a PSS solution. A stratified purposeful sampling approach was applied to select companies and interviewees (Voss 2009). In practice, this meant that the thesis supervisor connected the thesis team with suitable interviewees. The companies that participated in the interviews were all in the manufacturing business but with different products and service solutions. Either they were offering a product-oriented PSS or a use-oriented PSS. The companies operated in the construction machine industry, aerospace industry and the furniture industry. The interviews were conducted involving three representatives of those described companies who are responsible for integrating sustainability into the operations of their company and who had been involved in the development of the PSS solution. Based on the primary research and secondary research questions, especially the secondary research question number two was the frame for the preparation of the semi-structured interview questions. The questions were divided into main questions that should be asked during the interview and questions that served as probes. All the information that emerged from the interviews was collected through recordings, which

were later transcribed. The transcriptions of those interviews were sent afterwards to each interviewee for validation.

2.3 Structured- and Open Coding

The collected data from the systematic literature review and the semi-structured interviews are qualitative data. For the research analysis, an inductive analysis research approach was needed. By carrying out an inductive analysis approach, the goal was to identify core meanings, themes, categories and the most relevant information regarding a specific topic and enables to describe the state of the art of the current research/ stage of knowledge (Thomas 2006). This approach was appropriate for the aim of this study as the goal was to identify the state of the art about sustainability and PSS in the current research based on the systematic literature review and understand how sustainability within PSS is approached in practice, based on the semi-structured interviews. Therefore, a combination of structured coding and open coding methods was applied. Coding within qualitative research is a process where parts of data are marked or coded based on the content that they represent to make data comparable (Bazeley 2013).
Structured coding with defined categories or codes is a way of making huge data sets manageable (Namey et al. 2008). As this research conducted a systematic literature review, and there were three different researchers analysing the data, structural coding was a suitable method. Specific parts of the conceptual framework supported the process of structured coding. The framework used is the Framework for Strategic Sustainable Development (FSSD) and it aimed to ensure that the results which emerged from the literature review and the interviews regarding sustainability were systematically analysed. An analysis matrix was developed which was based on preliminary research regarding the topic of PSS and sustainability and the FSSD. The categories for the coding process were determined by drawing inductively on the system and success level part of the FSSD. After creating the categories in the analysis matrix, the review of the literature included a process of structured coding as the matrix was applied for analysing the data and no further changes were made for the analysis of the results from the systematic review.
For analysing the interviews, the same matrix was applied, but the researchers used a combination of structured coding by using the matrix, but also an open coding process. An approach of open coding was adopted with the aim to cover blind spots regarding the implementation and the management of a sustainable PSS revealed by the interviews, that the literature has not been able to point out. This approach was adopted because rather than reducing information, in comparison with structured coding, it enhances the organization of data through meaningful categories promoting a critical reflection on the results (Price 2012). In addition to structural coding, open coding was also needed as the research included semi-structured interviews. The interviewees were able to speak freely during the interviews. In order to be able to identify topics regarding the business perspective that the researchers were looking for or themes that emerged during the interviews an open coding approach was included.
In the following 2 sections, the application of the FSSD in this study and the matrix are introduced.

2.3.1 Criteria derived from the FSSD for the Analysis-Matrix

For analysing the identified results, a matrix was formed. The advantage of having the matrix was that it served as a shared mental model inside the group for the extrapolation of the information from the articles and the interviews. Furthermore, the matrix was not necessary

only to structure the information coming from the articles and the three interviews but also to standardise the data collection for each member of the group. In this way, it was ensured that the process of data analysis was systematic even though the work was distributed between the three team members.
The criteria were selected based on the following considerations regarding the system level and the success level of the FSSD.

System Level
Reflecting on the system level, the system perspective embodied by the multiple definitions in the literature were assessed. The system level consists of an understanding of the overall socio-ecological system, the complexity of the surrounding system, the sustainability challenges and the connected opportunities. Compared to other approaches like the triple-bottom-line approach with "People, Planet, Profit" it offers a different understanding of how the economic system is related to the environment system and the societal system. PSS as a business model is nested within the system of business models, which is nested within the economic system, which is in turn nested within society and which is part of the biosphere. Therefore, using the system level, the aim was to identify if the existing definitions acknowledge the role of sustainable PSS related to the overall sustainability challenge. To address this topic, the research was structured to identify those patterns conferring to the definitions the ability of pointing out the diverse relationships of the PSS within the triple-nested system.

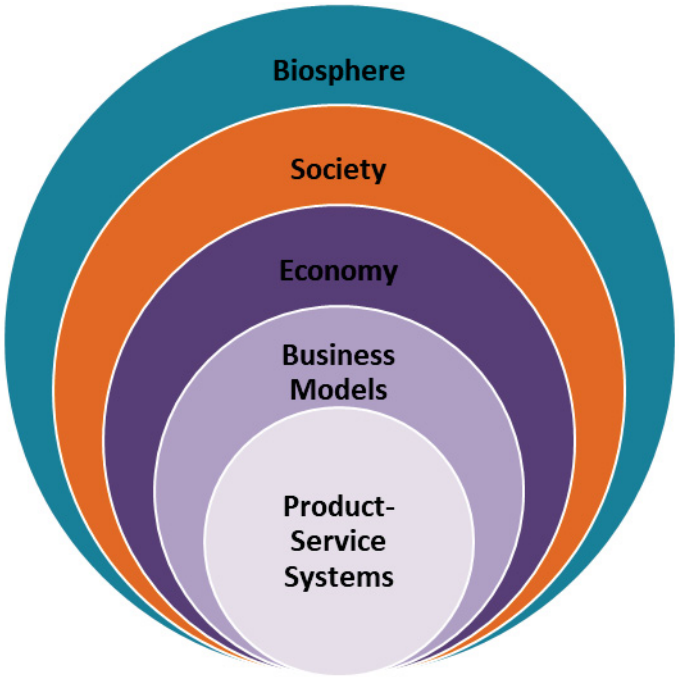


Figure 6: Business Model and PSS within the triple-nested system

Criteria for the system level
The definitions were evaluated in terms of which system perspective is applied. For this purpose, it was decided to analyse the definitions by looking at three factors:

- the model of sustainability adopted in the definition (related to the dimensions of sustainability regarding environment, social and economy)
- the stakeholders considered;
- the coverage of the life-cycle of the PSS.

The model of sustainability was considered as it represents the foundations of each sustainable PSS definition. It serves as an indicator of how the different dimensions of sustainability are respected within the design of sustainable PSS, how those dimensions are related to each other and how PSS is related to the socio-ecological system. This means that the definitions were assessed against the triple-nested system which is described by the FSSD (described in section 1.3).
Regarding the stakeholders, it was analysed if and how a sustainable PSS is considered to be interconnected with both internal and external stakeholders. For having a full system perspective integrated in a PSS solution it is important to reflect on the impacts a PSS can have on the stakeholders' network. It was specified both internally and externally because, for having a holistic view, a PSS should not be sustainable within the business itself only but also for all the stakeholders connected, such as suppliers or customers. A definition of sustainable PSS that considers sustainability both internally and externally covers the system perspective that is needed for including an SSD perspective.
Finally, each definition was analysed in terms of life-cycle perspective to see if and which parts of the life-cycle were addressed. A definition that covers all aspects of a life-cycle is likely to offer a holistic view on the PSS and sustainability.
This approach described was considered as a robust and comprehensive system overview from an SSD perspective for assessing the definitions.

Success Level
For the success Level it was investigated if the criteria are within the constraints of the 8 SP's or if it is possible that those criteria generate an understanding of sustainable PSS that would lead to a design of a PSS that contributes to a violation of one or more SP's (e.g. if social aspects aren't covered by the definition it can be assumed that the social aspects are a blind spot when designing a "sustainable" PSS). The criteria adopted in the literature and practice, for characterising a sustainable PSS were gathered and then compared with the definition of sustainability through the eight sustainable principles outlined by the FSSD, looking for and pointing out matches and gaps.

Criteria for the success Level
For the analysis on the success level, criteria that was identified as critical factors for sustainable PSS from the literature and from the interviews were analysed on the success level. First, the criteria were clustered within the ecological and social dimensions compared with, and connected to, the sustainability principles. From this, alignments and misalignments with the eight sustainability principles were identified. By applying this form of structural coding, strengths and weaknesses of each definition were identified from an SSD perspective. In the FSSD there is no explicit economic dimension of sustainability included in the eight Sustainability Principles. Therefore, the criteria in the literature were qualitatively assessed as coherent with the 8SPs if they might support the sustainability of the PSS, or incoherent, if they generate possible misalignments with the 8SPs.
After this phase, all the criteria identified in the literature were gathered and clustered for sustainability dimension.

Matrix applied for analysing the Interviews
In order to ensure coherence, for analysing the interviews, the same matrix was applied that was also used for analysing the literature. Strengths and weaknesses of both the definition and criteria were identified by using the criteria derived from the FSSD. Especially regarding the criteria, the results from the interviews were used to evaluate if the criteria found in the literature were complete and reasonable. By benchmarking the list of criteria with the findings from literature, it was possible to check if the suggestions from the practitioners were already covered by the literature or if the list needed additional criteria to be included.

2.3.2 Matrix for Data-Analysis

The matrix for the analysis was structured in 15 columns. Of those 15 columns, the first eleven columns were designed for the analysis on the system level. The last four columns covered the aspects for the analysis in the success level.
The first three columns are related to the anagraphical information of the articles, reporting the title, the year of publication and the name of the author (table 4).

Table 4: Anagraphical information of the articles

Article name	Year	Author
Designing Sustainable Energy for All	2018	Carlo Vezzoli, Fabrizio Ceschin, Lilac Osanjo, Mugendi K. M'Rithaa, Richie Moalosi, Venny Nakazibwe, Jan Carel Diehl
Product-Service System Design for Sustainability	2014	Carlo Vezzoli, Cindy Kohtala and Amrit Srinivasan

The 4th column reports the model of sustainability adopted by the author as a foundation for the definition of sustainable PSS (table 5). A model of sustainability can be the triple-nested system, the one used in the FSSD, the triple-bottom-line, a framework that incorporates three dimensions of performance: social, environmental and financial equally sustainability pillars (a similar approach to the triple-bottom-line). With this category it was also highlighted if a definition was not based on a specific concept of sustainability.

Table 5: Criteria 'Sustainability model'

Sustainability Model (e.g. triple-bottom-line)
Three pillars of sustainability, the economic with the environmental and the socio-ethical ones (similar to the triple bottom line)

From the fifth to the eighth column, information regarding the definition of sustainable PSS were collected (table 6). First of all, the definition itself of sustainable PSS was gathered in the fifth column. The sixth column reports if the definition was internally developed or adopted from external researches. More information regarding the different types of definition identified in the systematic research are explained in section 3.1. The seventh and eighth column show if the definition is related to a specific type of PSS, e.g. if the definition is related to the use-oriented PSS, or a specific industry, e.g. only to the energy industry.

Table 6: Criteria covering the definition of sustainable PSS

Definition of Sustainable PSS emerging from the article	Internal /External	Type specific	Ind. specific
S.PSS (Sustainable Product-Service System) is an offer model providing an integrated mix of products and services that are together able to fulfil a particular customer demand (to deliver a "unit of satisfaction"), based on innovative interactions between the stakeholders of the value production system (satisfaction system), where the ownership of the product/s and/or its life cycle responsibilities remain by the provider/s, so that the economic interest of the providers continuously seek new environmentally and/or socio-ethically beneficial solutions	Internal (re-arranged the 2014 definition)	N	N

The columns nine to eleven were created to reflect on the stakeholders and on the life-cycle (table 7). These columns report information not only derived from the definition itself but extracted from the whole article. The ninth and the tenth columns present data regarding the stakeholders considered. The ninth column shows if in the article internal stakeholders, e.g. employees, are considered. The tenth column does the same but for the external stakeholders e.g. the customers or the surrounding community.
The eleventh column, instead, was specifically designed for the life-cycle perspective of a sustainable PSS. Through this last column it was reported if the article considers the entire life-cycle of the PSS or not or just focused on specific phases.

Table 7: Criteria covering the Stakeholder and life-cycle

Int. Stake	Ext. Stake	Life Cycle
Y	Y	Y

The last four columns cluster the criteria reported in the articles a sustainable PSS should comply with (table 8). Those categories were especially designed for investigations of the success level. For each article, it was reported if and how the most used sustainability dimensions, (environmental, social and economic), were considered, and if additional specific dimensions were mentioned by the author. The specific criteria mentioned in the articles regarding each dimension were collected.

Table 8: Criteria of the sustainability dimensions

Article name	Environmental criteria	Social criteria
Product-service systems as a promising approach to sustainability: Exploring the sustainable aspects of a PSS in Brazil	1) Greenhouse gases emissions; 2) Renewable resources use; 3) Efficient use of resources; 4) Waste generation; 5) Energy consumption; 6) Efficient use of transport;	1) Health and safety; 2) Employment of labour;
	Economic criteria	**Additional criteria**
	1) Added value; 2) Operational costs;	PSS acceptance

To have a common base for benchmarking all the collected data, the same matrix was adopted also to report the data resulting from the interviews and only the anagraphical columns were neglected. One additional column was added from the interviews which covers additional considerations that a sustainable PSS should take into account from a business perspective (table 9).

Table 9: Additional criteria to have a business perspective for sustainable PSS

Definition of Sustainable PSS	Internal /External	Int. Stake	Ext. Stake	Life Cycle	Additional aspects regarding Business Perspective	Environmental criteria	Social criteria	Economic criteria
A sustainable PSS is a business model with integrating a holistic view that takes into account environmental, social and economic aspects in all the different phases of the life-cycle.	Internal	Y	Y	Y	- Take advantage of the technological innovation: integrate the technological advance within the industry in order to provide more successful, performant and sustainable PSS. - Connecting to customers and suppliers' systems and requirements, building long term relationships. From collaborations new technology innovations can emerge.	Reduced emissions (ideal goal zero emissions); limit use of natural resources; resource circularity; zero waste; landfill-free; material efficiency; choose or select the right kind of materials; eco-friendly use of the products; recycling and remanufacturing components of worn-out machines; refurbish machines to go into the second or third life; consider the correct life cycle impact in terms of transportation; not using acids, substances and chemicals that might be dangerous for peoples' health; energy optimization;	Health and safety of the operator; health, safety and wellbeing of the surrounding society; societal engagement; education training; occupational health and safety; fulfil all legal requirements;	Economically beneficial for all the stakeholders in the whole value chain

3. Results

In this chapter the results from the systematic literature review and the interviews are presented.

3.1 Results from Systematic Literature Review

The string line applied to the database SCOPUS generated an initial list of 516 articles. After the first screening process, the articles meeting the requirements of the filtering criteria were 113. The second screening phase led to a final list of 24 articles. Alongside the literature review, 3 interviews were carried out. Therefore, at the end of the process, the information emerging from 24 articles and 3 interviews were reported in the matrix and then analysed.
Table 10 summarizes the sources that were identified as the most relevant to this study.

Table 10: Three types of articles identified through SLR-process

Article includes:	Number of articles identified	References
DEFINITION	6	Sousa-Zomer and Cauchick-Miguel 2016, Ceschin 2014, Annarelli, Battistella, and Nonino 2016, Roy 2000, Hobson et al. 2018, Bhamra et al. 2018
DEFINITION+ CRITERIA	9	Vezzoli et al. 2018, Tukker and Tischner 2006, Santana, Barberato, and Saraiva 2010, Chou, Chen, and Conley 2015, Sousa-Zomer, and Cauchick-Miguel 2017, Chen 2018, Vezzoli, Kohtala, and Srinivasan 2014, Wever and Vogtländer 2015, Lee et al. 2012
CRITERIA	9	Xing, Wang and Qian 2013, Sundin, Nässlander, and Lelah 2015, Sousa-Zomer and Cauchick-Miguel 2015, Negri et al. 2016, Abramovici et al. 2014, Barquet, Seidel, and Kohl 2016, Hu et al. 2012, Kim et al. 2016, Chen et al. 2015

Three different types of articles were found that fulfilled the criteria of the first and second screening in the systematic literature review process and were therefore included in the analysis. The first category of articles included in the analysis comprises six articles which provide only a definition of sustainable PSS. There are three different ways of how the definitions are displayed in the articles. The definition could be either internally developed by the authors themselves e.g. like the definition of sustainable PSS from Ceschin (2014). Other definitions were built and developed based on different definitions from other studies e.g. the study from Bharma et al. (2018) developed their definition. In the article from Lee et al. (2012) the definition of sustainable was not explicitly stated but emerged as a definition by analysing the article.

In nine articles a definition and criteria that need to be considered for integrating sustainability in PSS were identified. Those articles contain a definition plus criteria that outline the context for sustainability for a PSS. The criteria address several aspects, primarily regarding the environmental, social and economic dimension that a sustainable PSS should cover. One example of those studies is the study presented by Chou, Chen, and Conley (2015).
Some articles did not include any definition but criteria that a sustainable PSS should cover. Those articles were included as well. The study of Barquet, Seidel, and Kohl (2016) is one example that presents criteria for sustainable PSS without a definition.
The following table (table 11) presents the number of criteria that were in total identified. The criteria might have content-wise overlappings, e.g. in a few articles there is criteria related to the material consumption or rather material reduction (Vezzoli, Kohtala, and Srinivasan 2014; Chen 2018). For the analysis, the criteria were cumulated (see table 15 in chapter 4). In general, four different categories of criteria were identified through the systematic literature review. The first category criteria cover the environmental dimension of sustainability of a PSS, the second covers the social dimension and the third category covers the economic dimension. From the literature review criteria that did not fit into one of the three categories were identified. These criteria were summarized under "additional criteria", the fourth category.

Table 11: Numbers of criteria identified through systematic literature review

	environmental criteria	social criteria	economic criteria	additional criteria
total amount of criteria identified in SLR (overlapping included)	104	116	44	39

3.2 Results from Interviews

From the interviews, the researchers were able to get a description of what a sustainable PSS can look like from the business perspective. Those insights were used to formulate a definition of sustainable PSS emerging from each interview (table 12). Regarding the general description of sustainable PSS, all practitioners state that a whole life-cycle perspective is needed. All the interviewees reported that, in order to ensure sustainability throughout the entire PSS life-cycle, it is necessary to establish a network of partnerships between the company and all actors taking part in the PSS value chain. Sustainability in contrast, is addressed in different ways. In the interview one, sustainability is addressed in the dimensions of environment, social and economic. Sustainability in interview two is related to environmental and economic aspects by focusing especially on the optimization of the production processes. In the interview three, sustainability is basically covered through environmental and social aspects within the life-cycle.

Table 12: Description of sustainable PSS from the interviews

Interviewee	Industry	Description of sustainable PSS
No. 1	Construction machine	A sustainable PSS is a business model with integrating a holistic view that takes into account environmental, social and economic aspects in all the different phases of the life-cycle.
No. 2	Aerospace	PSS becomes sustainable if it takes the whole life-cycle into account and optimize its production, for example by looking at the materials you use.
No. 3	Furniture	A sustainable PSS is a PSS circularly oriented, taking care of environmental and social issues along all the life-cycle (loops).

Besides the definitions of sustainable PSS emerging from the interviews, the researchers got insights of which criteria practitioners consider to integrate sustainability in product-service systems. Some overall criteria that should be integrated to develop a sustainable PSS commonly emerged from all the three interviews (table 13). Regarding the criteria that emerged from the interviews, some similarities in environmental and social criteria were identified. Especially regarding the environmental criteria, all interviewees stated to consider to lower emissions, to reduce the use of chemicals, to optimize the use of materials, thus enhancing more environmentally sustainability practices. In relation to social sustainability, all the interviewees are addressing this dimension, though with different levels of detail. One of the interviewees described that their company had developed in-house tools to address social sustainability, whereas the others adopt only some criteria mainly targeting the health and safety of employees and customers. Overall, one common criteria in relation to social sustainability was health and safety for the employees, suppliers and customers/users of the PSS solution. Other criteria instead were more specific in relation to the industry the companies are operating in.

Table 13: Similar criteria identified in interviews

Similarities regarding	Environmental criteria	Social criteria
	1) Reduced/ lower emissions 2) Material efficiency/ reduce amount of materials, 3) Reduce chemical use/ no chemical use	Health and safety for the 1) Employees, 2) Suppliers and 3) User/ customer

Some additional environmental criteria were mentioned in two out of the three interviews which were:

- extend the life of the product
- design closed loops for products/ components (recycling remanufacturing)
- resource circularity/ use of recycled materials
- right kind of materials/ material from renewable resources.

Besides those criteria that the companies had in common, differences were also identified. Some criteria in fact were more specific in relation to the business the companies are operating in. In table 14, those criteria are presented.

Table 14: Criteria mentioned in one out of three interviews

Criteria	Construction Equipment	Aerospace	Furniture
Environ-mental	1) Energy optimization 2) Correct life-cycle impact in terms of transportation 3) Landfill-free	1) Energy from renewable sources	
Social	1) Wellbeing of the surrounding society 2) Societal engagement 3) Education training for suppliers and customers		1) Inspire customer
Economic	1) Economic benefits for all the stakeholder in the value chain	1) Cheaper than the pure manufacturing/standard offering for both developers and customers	1) Effective maintenance/ repair costs;
Additional	1) Selection criteria for suppliers and customers to ensure sustainability in the whole life-cycle		1) Track information about maintenance operations, warranties, materials and second-hand market flow

All the interviewees pointed out that economic features lay the foundation for a successful and sustainable PSS but a common pattern regarding criteria for economic sustainability was not identified.

The last important theme that emerged from the interviews concerned innovation. Innovation is a critical factor that must be considered while developing a PSS. However, specific criteria regarding this theme did not emerge through the interviews.

4. Results Analysis and Discussion

In this chapter the results from the systematic literature review and the interviews are analysed and discussed. From those findings, a definition of sustainable PSS integrating a strategic sustainable development perspective and a list of sustainability design criteria were developed. In section 4.1, the systems perspective conferred to the definitions of sustainable PSS is evaluated by applying the system level of the FSSD. Section 4.2 explores the application of the success level of the FSSD to the design criteria that emerged from the literature review. Next, in section 4.3 the pattern that emerged from the interviews is analysed and integrated into the findings of the literature. The definition of sustainable PSS and the final list of design criteria are reported in section 4.4. Finally, in section 4.5, strengths and weaknesses of the research are presented.

4.1 System Level Analysis of Literature

In the system level analysis, the definitions of sustainable PSS which enhanced a systems perspective were assessed (Table 15). Only the articles reporting a definition, either explicitly or implicitly, were considered. For this reason, fifteen articles were taken into consideration. By referring to the information reported in the matrix (appendix A and B), each definition was assessed through three different criteria. For this analysis, the category sustainability model was restructured into three different sub-categories representing the sustainability dimensions suggested by the FSSD within the triple-nested system: environment (En), society (So) and economy (Ec). In this way, for each definition, it was clarified which specific dimensions the definitions cover. Additionally, the analysis regarding the category stakeholder, considered the terms Internal stakeholder (Int) and external stakeholder (Ext) and the category life-cycle.

Table 15: Analysis of the academic definitions of sustainable PSS

Article	Definition of Sustainable PSS emerging from the article	sustainability model			Int	Ext	LC
		En	So	Ec			
Vezzoli et al. 2018	S.PSS (Sustainable Product-Service System) is an offer model providing an integrated mix of products and services that are together able to fulfil a particular customer demand (to deliver a "unit of satisfaction"), based on innovative interactions between the stakeholders of the value production system (satisfaction system), where the ownership of the product/s and/or its life cycle responsibilities remain by the provider/s, so that the economic interest of the providers continuously seek new environmentally and/or socio-ethically beneficial solutions	Y*	Y	Y	Y	Y	Y
Tukker and Tischner 2006	Sustainability is not an automatic mechanism built into the PSS concept, but it depends on many conditions. A "sustainable" PSS is achievable only if sustainability considerations are integrated into all the steps of a PSS development and design process, that its market launch is carefully prepared in order to be successful, and finally that the solution on the market is reviewed relating to economic, environmental and social impacts. A "sustainable" PSS decouples economic growth from negative environmental impacts reaching the Factor X.	Y	Y	Y	Y	Y	Y
Santana, Barberato and Saraiva 2010	PSS is considered as a tool to enhance environmental sustainability. It must be integrated with both LCA and social and economic criteria in order to achieve a full sustainability.	Y	Y	Y	Y	Y	Y
Chou, Chen and Conley 2015	A sustainable PSS means that product-service solutions should generate satisfactory value for customers and fulfils the sustainability requirements at the same time.	Y	Y	Y	Y	Y	Y
Sousa Zomer and Cauchick Miguel 2016	A sustainable PSS is an eco-efficient PSS sustainable on both the supply side (before the consumption) and the consumption side. In order to integrate the consumption side, social practices must be taken into consideration.	Y	Y	Y	Y	Y	Y
Sousa Zomer and Cauchick Miguel 2017	To be considered as a real sustainable solution, a PSS should provide environmental, economic, and social benefits throughout the whole life cycle.	Y	Y	Y	Y	Y	Y
Chen 2018	A sustainable PSS is an offer model connecting value network between different stakeholders and integrating sustainability visions into the service context.	Y	Y	Y	Y	Y	Y
Vezzoli, Kohtala and Srinivasan 2014	An eco-efficient PSS is an offer model providing an integrated mix of products and services that are together able to fulfil a particular customer demand (to deliver a 'unit of satisfaction') based on innovative interactions between the stakeholders of the value production system (satisfaction system), where the economic and competitive interest of the providers continuously seeks environmentally beneficial new solutions.	Y	Y	Y	Y	Y	N
Wever and Vogtländer 2015	A sustainable PSS (SusPSS) consists of an integration of services to a low eco-cost product, thus increasing its value/production costs ratio. Eco-costs are virtual costs representing the eco-burden of a product or service, with the understanding that eco-costs may well become real costs in the future through legislation internalizing this burden.	Y	Y	Y	Y	Y	N**
Ceschin 2014	A sustainable PSS can be defined as a PSS where the economic and competitive interest of the providers continuously seeks environmentally beneficial new solutions, while maximising social well-being, equity and cohesion.	Y	Y	Y	Y	Y	N

Lee et al. 2012	A PSS is environmentally sustainable when 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. That PSS is socially sustainable when the PSS is sustainably and actively acceptable to socio improving public welfare without invalidating social justice. That PSS is economically sustainable when the PSS is sustainably operational, fulfilling the economic motivation of each stakeholder structurally.	Y	Y	Y	Y	Y	N
Annarelli, Battistella and Nonino 2016	General definition of PSS (considered intrinsically sustainable): PSS is 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.	Y	Y	Y	Y	Y	N
Bharma et al. 2018	Sustainable PSS are part of a radical transformation of our economic system from a consumption model and a linear approach to production to one less dependent on physical resources (p.231). A sustainable PSS should also have environmental, social, and economic impact in ways that ensure sustainable living for all (p.232)	Y	Y	Y	Y	Y	N
Roy 2000	Sustainable product-service systems are models designed and marketed to provide customers with a particular result or function without them necessarily having to own or buy physical products in order to get that result. In addition, the design of new product-service systems may involve the development or use of 'eco-efficient' products that are more efficient in their use of energy and materials and generate less pollution and waste.	Y	N	N	Y	Y	N
Hobson et al. 2018	The concept of Sustainable Product Service Systems (SPSS) is about reconsidering how material and service needs are being and/or can be met, working towards goods and parallel services that are more environmentally benign and materially/energetically efficient.	Y	N	N	Y	N	N
Note for the reader: *Y (definition fulfils criteria) **N (definition does not fulfil criteria)							

The analysis shows that seven of the fifteen articles have definitions that include all the three investigated aspects. Since they rely all on the triple-nested systems and consider both internal and external stakeholders throughout the whole life-cycle, these definitions provide a systems perspective on the PSS. Therefore, these were adopted as foundations for the development of a new definition of sustainable PSS. Six definitions, instead, lack a full life-cycle perspective. Some of them reflected only certain aspects of the PSS life-cycle, like the value production system (Vezzoli, Kohtala, and Srinivasan 2014), whereas others are not targeting the life-cycle at all (Lee et al. 2012). These six articles were however still used as complementary foundation for the developed definition. Finally, two articles contained definitions of sustainable PSS limited to the environmental dimension of sustainability. Due to their lack of a systems perspective, they were not considered for the realization of the final definition.

4.2 Success Level Analysis of Literature

In the Framework for Strategic Sustainable Development, sustainability is defined by the eight sustainability principles (Broman and Robért 2017). As already described in section 1.3, those principles act as boundary conditions outlining sustainable scenarios for businesses (Robért et al. 2018). A sustainable PSS should be within those constraints and in alignment with the principles.

Aiming to support PSS designers in integrating sustainability systematically, an investigation on how the sustainability principles can be addressed was conducted. The criteria emerged from the systematic literature review were analysed and those aspects characterizing PSS sustainability were identified. As a result, two lists of environmental and social criteria were generated which designers can use as guidance to develop sustainable PSS.

From the analysis, many ways to assess the sustainability of a PSS were found. In the literature there are articles with criteria that focused on the environmental dimension of sustainability. The sustainability-oriented multidimensional value assessment model for product-service development, suggested by Xing, Wang and Qian (2013), addresses the environmental dimension through a set of indicators targeting the material and the energy flows, pointing out the environmental loads (emissions, waste, etc.) and the relative environmental impacts during the life-cycle of a PSS. However, the model excludes activities such as transportation and installation due to the small duration or quantity of their deployment, even though they can generate unsustainable impacts. Therefore, although it targets SP1 through indicators of energy and material reduction and SP2 through indicators of artificial by-products reduction, this model was assessed as partially aligned with the environmental dimension. The social dimension of sustainability is not considered at all by the model.

At the same time, articles only focusing on the social dimension of sustainability, also emerged from the literature review. Sousa Zomer and Cauchick Miguel (2017), by applying the Social Life Cycle Assessment (SLCA) to PSS, proposes a hotspot-based approach to forecast the social impacts on stakeholders during the life-cycle of a PSS solution in the design process. The model is based on a set of social sustainability criteria, specific for each stakeholder, clustered for each life-cycle phase. From the comparison between these criteria and sustainability principles, the model shows a comprehensive vision of social sustainability, considering all the social SPs. For example SP4 is addressed by criteria of health and safety for employees, customers and the surrounding community; SP5 is addressed by criteria of empowerment and integration of customers in the design and upgrade of the PSS; SP6 is addressed by criteria of knowledge transfer; SP7 is addressed by the criterion of broadening the access to good and services to the entire society; SP8 is addressed by criteria of community and societal engagement and cultural heritage safeguard. Despite the fact that it offers a full perspective on social sustainability, the model needs to be integrated with also an environmental perspective in order to provide a full SSD perspective. Therefore, the model was evaluated as in alignment with only the social dimension of sustainability.

Models integrating all sustainability dimensions, environmental, social and economic, were found from the literature review. For example, Lee et al. realized a dynamic and multidimensional sustainability measurement model for PSS based on the triple-bottom-line (Lee et al. 2012). Although sustainability is systematically addressed by criteria for the environmental, social and economic dimensions, an adequate SSD perspective is not offered. Indeed, from the comparison with the sustainability principles, the model is covering only SP1 through criteria of energy and emissions reduction and SP4 through criteria of health and safety and social well-being. Therefore, the model offered by Lee et al. was assessed as partially in alignment with the environmental and social sustainability outlined by the 8SPs.

Another example of comprehensive model was found in Tukker and Tischner (2006). By adopting the Methodology for Product-Service System Development (Tukker and Tischner 2006), design teams can improve PSS sustainability already in the design through a set of criteria targeting the potential environmental, social and economic impacts of a PSS solution. By pointing out the potential environmental benefits in terms of resource reduction and biocompatibility, and the social benefits in terms of health, co-operation, social equity, and promotion of sustainable behaviour, the model was recognized as covering all the environmental and social aspects of the SPs. For this reason, it was assessed as in alignment with the FSSD definition of sustainability and providing an SSD perspective.

Despite the fact that last model mentioned might have already provided a comprehensive vision of success for PSS sustainability, a systematic investigation on the criteria reported in the literature was conducted. In order to have a wider overview on them, the criteria adopted in 18 selected models concerning the sustainability of PSS were analysed. First, by applying the FSSD, all the criteria identified were re-grouped into the four macro-categories environment, social, economy and additional depending on which dimension they were addressing from the perspective of the eight sustainable principles. For example, the criteria about health, clustered into the environmental aspects in the article of Sundin, Nässlander and Lelah (2015), were moved to the social category. Then, all the criteria were clustered into sustainability principles categories based on the similarities between them. After the clustering activity, all the similar criteria were merged: e.g. the criterion waste reduction was included into the criterion waste minimization.
This process has led to two lists of environmental and social criteria. Table 16 and table 17 report all the criteria, grouped for reference SP, followed by the articles they were derived from.

Table 16: Environmental criteria list derived from literature review (the numbers represent the reference number in the final matrix).

Environ-ment	**PSS Environmental SUSTAINABILITY CRITERIA**	**REFERENCES**
SP1	Material life maximization	Vezzoli et al 2018; Sousa and Miguel 2015; Santana, Barberato, and Saraiva 2010; Abramovici et al. 2014; Chong-Wen Chen 2018
	Resource minimization	Vezzoli et al 2018; Vezzoli et al 2014; Tukker and Tischner 2006; Wever and Vogtländer 2015; Sousa and Miguel 2015; Santana, Barberato, and Saraiva 2010; Abramovici et al. 2014; Chong-Wen Chen 2018
	Maximisation of recycled material used	Sundin, Nässlander, and Lelah 2015
	Resource renewability	Vezzoli et al 2018; Sousa and Miguel 2015; Santana, Barberato, and Saraiva 2010; Negri et al. 2016; Allen Hu et al. 2012; D. Chen et al. 2015
	Energy minimization	Vezzoli et al 2018; Vezzoli et al 2014; Wever and Vogtländer 2015; Sundin, Nässlander, and Lelah 2015; Sousa and Miguel

		2015; Santana, Barberato, and Saraiva 2010; Abramovici et al. 2014; Lee et al. 2012; D. Chen et al. 2015; Chon-Wen Chen 2018
	Energy recovery	Vezzoli et al 2018; Santana, Barberato, and Saraiva 2010
	Emissions minimization	Xing, Wang, and Qian 2013; Sousa and Miguel 2015; Santana, Barberato, and Saraiva 2010; Abramovici et al. 2014; Lee et al. 2012
	Transportation/distribution minimization	Vezzoli et al 2014; Tukker and Tischner 2006; Wever and Vogtländer 2015; Sousa and Miguel 2015; Santana, Barberato, and Saraiva 2010
SP2	Product Lifespan maximisation	Vezzoli et al 2018; Vezzoli et al 2014; Tukker and Tischner 2006; Xing, Wang, and Qian 2013; Sundin, Nässlander, and Lelah 2015; Santana, Barberato, and Saraiva 2010; Chou, Chen, and Conley 2015
	Product Use intensification	Vezzoli et al 2018; Vezzoli et al 2014; Sundin, Nässlander, and Lelah 2015
	Resource biocompatibility	Vezzoli et al 2018; Vezzoli et al 2014; Tukker and Tischner 2006; Santana, Barberato, and Saraiva 2010; Negri et al. 2016
	Resource toxicity minimization	Vezzoli et al 2018; Vezzoli et al 2014; Santana, Barberato, and Saraiva 2010; Negri et al. 2016; Abramovici et al. 2014; Kim et al. 2016
	Effluents minimization	Santana, Barberato, and Saraiva 2010
	Waste minimization	Vezzoli et al 2014; Tukker and Tischner 2006; Santana, Barberato, and Saraiva 2010
	Amount of recuperation of waste/waste valorization	Sundin, Nässlander, and Lelah 2015
	Maximize the number of products being recycled at the end-of-life	Sundin, Nässlander, and Lelah 2015
	Design for repair and modular design	Xing, Wang, and Qian 2013; Santana, Barberato, and Saraiva 2010; Negri et al. 2016; Abramovici et al. 2014; Allen Hu et al. 2012
SP3	Minimize water consumption	Sundin, Nässlander, and Lelah 2015
	Minimize soil erosion	Negri et al. 2016
	Restore environmental resources	D. Chen et al. 2015

Table 17: Social criteria list derived from literature review.

Society	PSS SOCIAL SUSTAINABILITY CRITERIA	REFERENCES
SP4	Health and safety care and prevention (of employees, customer, stakeholders, community)	Tukker and Tischner 2006; Sousa-Zomer and Cauchick-Miguel 2017; Santana, Barberato, and Saraiva 2010; Abramovici et al. 2014; Chou, Chen, and Conley 2015; Allen Hu et al. 2012; Kim et al. 2016; Lee et al. 2012; Chong-Wen Chen 2018
	Improve employment/working conditions	Vezzoli et al 2014; Tukker and Tischner 2006; Sousa-Zomer and Cauchick-Miguel 2017; Santana, Barberato, and Saraiva 2010; Chou, Chen, and Conley 2015; Kim et al. 2016; D. Chen et al. 2015; Chong-Wen Chen 2018
	Improve quality of life	Tukker and Tischner 2006; Allen Hu et al. 2012; Kim et al. 2016; D. Chen et al. 2015; Chong-Wen Chen 2018
SP5	Feedback mechanism with customer	Sousa-Zomer and Cauchick-Miguel 2017
	Involve customers in the development	Barquet et al. 2016
	Empower customer, stakeholders and the community	Sousa-Zomer and Cauchick-Miguel 2017; Allen Hu et al. 2012
	Regenerate/empower/valorize local initiatives/resources	Vezzoli et al 2014; Barquet et al. 2016; Kim et al. 2016
SP6	Knowledge transfer/awareness to customers	Sousa-Zomer and Cauchick-Miguel 2017; Barquet et al. 2016; Allen Hu et al. 2012
	Training activities for employees	Abramovici et al. 2014
	Maintain/increase employment	Abramovici et al. 2014; Barquet et al.2016; Allen Hu et al. 2012; Kim et al. 2016
	Promote innovation	Barquet et al. 2016
SP7	Broaden access to goods and services	Sousa-Zomer and Cauchick-Miguel 2017; Barquet et al. 2016
	Improve equity and justice in relation with stakeholders (society/global perspective)	Vezzoli et al 2018; Vezzoli et al 2014; Tukker and Tischner 2006; Allen Hu et al. 2012
	Verify the ownership rights (of the resources)	Santana, Barberato, and Saraiva 2010

	Favor/integrate the weak and marginalized	Vezzoli et al 2014; Barquet et al. 2016
	Employees gender equality	Chou, Chen, and Conley 2015; Kim et al. 2016
	Respect and safeguard cultural diversity (society/local perspective)	Tukker and Tischner 2006; Sousa-Zomer and Cauchick-Miguel 2017; Kim et al. 2016
SP8	Enable responsible/sustainable consumption	Vezzoli et al 2014; Tukker and Tischner 2006; Allen Hu et al. 2012; Kim et al. 2016
	Improve social cohesion (promote cooperation)	Vezzoli et al 2018; Vezzoli et al 2014; Sousa-Zomer and Cauchick-Miguel 2017
	Community engagement	Sousa-Zomer and Cauchick-Miguel 2017
	Public (governmental) commitment to sustainability issues	Sousa-Zomer and Cauchick-Miguel 2017

The 20 environmental criteria resulted represent 20 different aspects which need to be addressed when developing an environmentally sustainable PSS. Within the category SP1 there are four criteria about resource use and four criteria regarding energy consumption and related impacts. SP1 is addressed through reducing the amount of materials used, through extending their life, through adopting more renewable resources and through introducing more recycled materials into the PSS life-cycle rather than virgin ones. Similarly, due to that, the energy system currently relies mostly on fossil fuels, through minimizing or recovering the amount of energy used, minimizing the need of transportation and minimizing the level of emissions, the concentration of substances extracted from the lithosphere into the biosphere can be reduced.

SP2 category clusters nine criteria, targeting multiple aspects for the prevention of the systematic increase in concentration of artificial substances into the biosphere. The first two criteria, product lifespan maximization and product use intensification, aim to reduce the production of PSS hardware. Indeed, by extending their time life and by intensifying their use, the physical amount of PSS hardware could decrease. The criteria of resource biocompatibility and toxicity minimization address the need of using the right materials, thus promoting the use of more eco-friendly and natural resources rather than producing artificial ones that might be toxic and dangerous for the environment. The criterion about the effluents minimization suggests monitoring and preventing the release in nature of artificial liquid flows, such as oils, or water flows contaminated by artificial substances. Then the last four criteria concern the reduction and the prevention of waste generation. By minimizing and recovering waste, recycling products and applying design for reuse for the PSS components, systematic increase in concentration of artificial substances into the biosphere could be delimited.

Only three criteria address SP3. The first two address the overexploitation of the natural resources water and soil, whose generate sustainability issues like water scarcity and soil erosion. The third one promotes the restoration of environmental resources, thus positively impacting SP3.

Concerning social sustainability 21 criteria were selected. Within the SP4 category, the structural obstacles to health are addressed by three criteria. The first two criteria reflect on the health and safety of the multiple stakeholders along the PSS life-cycle, with a specific focus on the employee working conditions, whereas the third criterion addresses the topic of quality of life, PSS can improve social conditions, thus allowing more people to meet their basic needs regarding health and safety.

SP5 cluster constitutes of four criteria. The first two affects the influence of customer on the PSS provider operations. When contributing to the design and to the upgrade, customer has higher decision-making power on the PSS. The last two, empower customer, stakeholders and community, and regenerate/empower/valorise local initiatives/resources have a wider perspective, targeting directly the societal structural obstacle to influence.

There are four criteria clustered into SP6 category: transfer knowledge/awareness to customer, training activities for employees, maintain/increase employment and promote innovation. By transferring knowledge to customers and offering training activities for the employees, the PSS promotes individual learning for many actors along the life-cycle. As well by maintaining or increasing the employment, structural obstacles about competence for workers are prevented. Finally, the criteria about the promotion of innovation was included into this category because a PSS continuously seeking innovation, throughout all the phases of the life-cycle, offers chances for mutual learning amongst the multiple actors connected to the PSS.

The six criteria regarding SP7 aim to tackle the structural obstacles of society exposing people to partial treatment. A PSS, first of all, should be designed to allow the access to goods and services for more people. Then, a socially sustainable PSS, should promote social equity during all its life-cycle, especially where the raw materials are withdrawn, verifying their ownership rights. At the same time, the marginalized and the weak people categories and employment equity (e.g. employees' gender and age equality) should be taken into account, trying to promote a positive impact to the structural obstacles established in the society. Finally, in order to ensure a respectful PSS and fair operations, cultural diversity should be addressed and safeguarded.

Criteria enabling the creation of individual and the co-creation of common meaning fall into the category SP8. A socially sustainable PSS should promote sustainable behaviours, especially regarding consumption to all the society. In addition to that a criterion concerning social cohesion was reported. Collaboration between different stakeholders is a way of co-creating meaning and impact positively on the society through the PSS. The last two criteria consider the engagement of both the local communities and of the governments the PSS affects to sustainability issues, thus promoting communitarian purposeful actions.

When combined, the criteria provide a full system perspective. On the contrary, if pursued independently, certain criteria may lead to unintended consequences. While maximising the compliance with an SP, the same criteria can cause misalignments to another, thus generating sustainability sub-optimizations (Byggeth and Hochschorner 2006). For example, the criteria "Product lifespan maximisation" might be pursued by adopting long lasting toxic chemicals, thus impacting negatively on employee's health and violating SP4. However, when combined with the criteria "Resource toxicity minimization", the use of toxic substances is prevented, thus ensuring more sustainable results. Therefore, the criteria must be considered

simultaneously, thus conferring to designers a full system perspective on PSS sustainability. In order to ensure a full perspective on sustainability, these criteria must also be adopted along the whole PSS life-cycle. Indeed, a PSS fulfilling all the criteria in only certain phases cannot be defined as sustainable. As an example, a PSS may be manufactured complying with all the criteria, while relying on unsustainable supply chains or leading to unsustainable consumption and disposal. Therefore, these criteria must be addressed by all the actors taking part in the PSS life-cycle.

As results of the analysis of the literature, also a set of economic criteria and a set of other criteria have emerged (appendix D). The economic criteria were not as intensively investigated as the environmental and the social aspects, because the FSSD doesn't provide boundary conditions to systematically assess economic sustainability, unlike it does for the environment and the social one. Economic criteria are fundamentally based on the concept of value, so the only economic criterion emerged regarding sustainability for a PSS is to provide value for all the actors involved in its value chain, while being aligned with the overarching environmental and social sustainability criteria. Therefore, when designing a sustainable PSS, designers should also consider the economic impact of the PSS on all the actors contributing to its realization, thus ensuring a PSS economically sustainable. The other criteria were reported but not structurally adopted for the analysis because often incompatible with the eight sustainability principles.

4.3 Interview Analysis

By analysing the interview data through the lens of FSSD's system and success level, some patterns characterizing the business perspective on the theme of sustainable PSS were detected.

As described in section 3.2, the interviewed companies highlighted the importance of economic features that a sustainable PSS should be based on. Therefore, economic sustainability, embodied as the concept of value, for both companies and stakeholders should represent the first step of the design of a PSS: a PSS which is not economically beneficial cannot be sustainable within the business context.

Regarding the environmental and social dimensions of sustainability, some common patterns were identified. Although some social criteria emerged from the interview with practitioners, it was clear that social sustainability is more difficult to address when developing a sustainable PSS. Therefore, a comprehensive set of criteria would help companies in reducing their social impacts.

Collaboration is another recurring theme. Through partnerships with organizations that share same values, PSS providers can guarantee the fulfilment of the sustainability criteria during the entirety of its life-cycle. Furthermore, by developing visions of sustainable success together, companies can truly engage customers and suppliers in adopting more sustainable behaviours. Therefore, through cultivating long-term relationships, companies may ensure sustainability during all the life of the PSS and even promote more sustainable practices.

Based on the findings from the interviews four criteria gathered from the literature review were adjusted. These adjustments are presented in the table below (table 18).

Table 18: Criteria redefined after the interviews

Society	PSS SOCIAL SUSTAINABILITY CRITERIA
SP5	Feedback mechanism with customers and suppliers
	Involve customers and suppliers in the development
SP6	Knowledge transfer/awareness to customers and retailers
	Training activities for employees and partners

Two criteria regarding SP5 and two criteria regarding SP6 were modified by including additional stakeholders. Suppliers were added to the criteria "Establish feedback mechanism with customers" and "Involve customers in the development", because suppliers should be involved as much as customers in the design and upgrade of a PSS. Similarly, a company should transfer knowledge about the correct use of the PSS not only to the customers but also to retailers, who provide users with developers' guidelines. Therefore, retailers were added to the criterion "Knowledge transfer/awareness to customers". Finally, training activities should also be planned for partners, in order to enhance their skills and their knowledge, thus promoting improvements throughout all the PSS life-cycle. Partners were then included in the criterion "Training activities for employees".

4.4 Proposal for a new Definition of Sustainable PSS

Deriving from the analysis of the current definitions of sustainable PSS, through the application of the FSSD, and the investigation into the business perspectives of three PSS providers, the following definition of sustainable PSS is suggested:

"a PSS designed within robust sustainability constraints providing benefits to stakeholders during its entire life-cycle."

This definition points out three key features for a sustainable PSS:

- **Respect sustainability constraints.** A sustainable PSS must be in alignment with all the eight sustainable principles. At the same time, a sustainable PSS must be economically beneficial, generating value for all the actors taking part in the PSS value chain.

- **Integrate stakeholders' perspective**: a sustainable PSS is sustainable for all the stakeholders. In other words, to be defined as sustainable, a PSS needs to provide positive impacts to all stakeholders internal and external to the company. Therefore, a sustainable PSS must be designed not only considering the sustainability of its operations and the impacts on internal stakeholders, like employees or shareholders, but also the impacts it has on customers, suppliers and on the surrounding society.

- **Consider the whole life-cycle**: a sustainable PSS is sustainable in all the phases of its life-cycle. For this reason, a sustainable PSS must integrate a holistic life-cycle perspective, addressing sustainability since the raw material extraction to its end of life.

4.5 Proposed Tool

The final list of environmental and social criteria clustered for each sustainability principle was developed (figure 7). This list gathers all aspects regarding PSS sustainability, that designers should consider for complying with all the sustainability principles.

Ecological Principles

SP1:

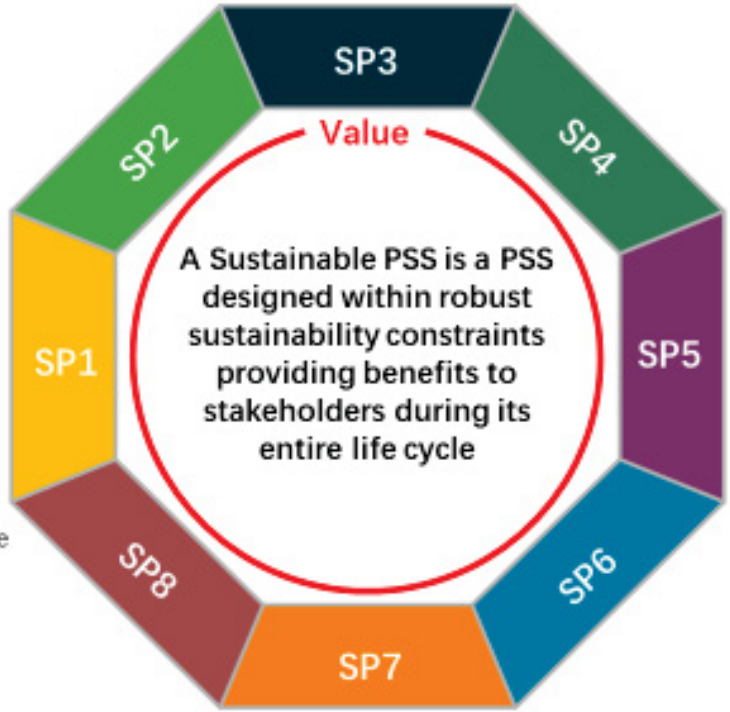
- ✓ Material life maximization
- ✓ Resource minimization
- ✓ Maximization of recycled material used
- ✓ Resource renewability
- ✓ Energy minimization
- ✓ Energy recovery
- ✓ Emissions minimization
- ✓ Transportation/distribution minimization

SP2:

- ✓ Product Lifespan maximization
- ✓ Product Use intensification
- ✓ Resource biocompatibility
- ✓ Resource toxicity minimization
- ✓ Effluents minimization
- ✓ Waste minimization
- ✓ Maximize the recuperation of waste/waste valorization
- ✓ Maximize the number of products being recycled at the end-of-life
- ✓ Introduce design for repair and modular design

SP3:

- ✓ Minimize water consumption
- ✓ Minimize soil erosion
- ✓ Restore environmental resources



Economic criteria: a Sustainable PSS provides value for all the actors involved in its value chain, while being aligned with the overarching environmental and social sustainability criteria.

Social Principles

SP4:

- ✓ Health and safety care and prevention (of employees, customer, stakeholders, community)
- ✓ Improve employment/working conditions
- ✓ Improve quality of life

SP5:

- ✓ Establish feedback mechanism with customers and suppliers
- ✓ Involve customers and suppliers in the development
- ✓ Empower customer, stakeholders and the community
- ✓ Regenerate/empower/valorize local initiatives/resources

SP6:

- ✓ Transfer knowledge/awareness to customers and retailers
- ✓ Training activities for employees and partners
- ✓ Maintain/increase employment
- ✓ Promote innovation

SP7:

- ✓ Broaden access to goods and services
- ✓ Improve equity and justice in relation with stakeholders (society/global perspective)
- ✓ Verify the ownership rights (of the resources)
- ✓ Favor/integrate the weak and marginalized
- ✓ Respect employment equity
- ✓ Respect and safeguard cultural diversity (society/local perspective)

Sp8:

- ✓ Enable responsible/sustainable consumption
- ✓ Improve social cohesion (promote cooperation)
- ✓ Promote community engagement
- ✓ Promote public (governmental) commitment to sustainability issues

Figure 7: Final list of environmental and social criteria

4.6 Reflection on Research Approach

Regarding the methodological approach of this research, the following research limitations and research strengths for each research element were identified.

Systematic literature review
Many articles that were identified through the systematic literature review had a definition of sustainable PSS but a lot of those definitions were cited from other sources. Therefore, a few important sources weren't covered in the conducted research as the research team decided to only focus on articles that were identified through the applied string to have a reasonable scope regarding the time constraints. Furthermore, working on a systematic literature review in a team of three different researchers was both beneficial and challenging at the same time. Based on the scope of the database, it was also not investigated if there are existing models or frameworks for implementing sustainability in PSS offered by consulting companies or practitioners.

By conducting a systematic literature review, a methodological tool was used that ensured a systematic process which was clear, transparent and replicable. With using the database SCOPUS the biggest database for scientific researches was chosen to identify the most relevant articles for the investigated research. The Matrix but also the search protocol served as a shared mental model within the research group to guarantee that the process of doing the systematic literature review was done in a way that is replicable and transparent.

Interviews
Interviews were conducted with representatives from companies who were responsible for ensuring that sustainability was considered in PSS. Therefore, the criteria that emerged from practice are broad. The criteria serve as descriptions of what needs to be considered and not how it is actually conducted. Also, the interviewees are working for organizations in different industries and with different offerings. More in-depth researches can be conducted within the same industry in order to identify common patterns, thus providing more precise criteria that can be more valuable for the practitioners in a specific industry. A similar reasoning can be adopted about the type of PSS. Through the interviews, only product-oriented and use-oriented but not the result-oriented PSS were covered.

The interviewees had experiences with sustainability and PSS and were therefore suitable. For conducting the interviews, one hour was scheduled for each interview. This gave the researchers enough time to ask the questions to gain the deep understanding that was needed to cover a business perspective for creating the shared understanding of sustainable PSS.

Structural & open coding
The used framework, the FSSD, for deriving criteria for the coding and conducting the analysis doesn't address economic issues as it is a framework that was never designed to assess economic sustainability. Therefore, the criteria emerged from the literature and the interviews about economy or additional criteria that did not directly fit to a specific SP were not assessed through the Sustainability Principles.

This thesis aimed to raise a common understanding by providing a definition of what sustainable PSS is and to show how the developed definition can be used. Through the list of guiding criteria, sustainability can be systematically targeted by companies. However, further

and narrowed research can be implemented to develop consistent guidelines for businesses based on the criteria emerged from this thesis. In this way, sustainability could be strategically integrated in companies' operations. Those guidelines could potentially be developed for assessing also trade-offs between different PSS alternatives, thus leading companies in realizing the "most sustainable" PSS amongst the alternatives.
The proposed definition of sustainable PSS and the criteria can be validated or refined through e.g. a survey study or further interviews with researchers and businesses.

Using the FSSD as a model helped the research team in having a definition of sustainability based in boundary conditions. The boundaries, embodied through the eight sustainability principles, served as an optimal analytical tool. With the 8SP the criteria from the research and the practitioner were assessed and a list of criteria that is likely able to help practitioners was created. Those criteria support in providing awareness which critical factors for a sustainable PSS should be considered to be align with the sustainability boundaries offered by the FSSD.

5. Conclusions and Recommendations

The purpose of this thesis was to enable designers to be more aware of how to integrate strategically and systematically sustainability into PSS solutions. In the existing academic literature, there was no common understanding of sustainable PSS. Therefore, this research was conducted to provide a unified definition of sustainable PSS and a set of criteria addressing the impacts on sustainability of PSS.

By answering the question "What is the definition of a sustainable PSS that integrates a strategic sustainable development perspective? this thesis suggests a definition of sustainable PSS built on the system level of the FSSD, thus conferring to designers a system thinking mindset for the development of a PSS. This kind of mindset allows designers to consider the interconnectedness of the PSS with all the stakeholders within the larger socio-ecological system and the impacts it generated throughout its whole life-cycle.
Then, the theme of the critical elements that firms should consider in the design of a PSS to comply with the definition suggested was investigated. To answer the need just mentioned, this thesis proposes a list of criteria relying on the principled based definition of sustainability offered by the FSSD and tailored on the theme of PSS. For its development, an investigation of the literature was combined with interviews to PSS providers, thus integrating in the list both an academic and a business perspective. By adopting this list of criteria addressing each sustainability principle, designers can systematically integrate sustainability into their PSS solutions. Sustainability principles can result vague to beginners, therefore, having a clear list of tangible criteria, would help designers what to target in order to meet the requirements of the principles. At the same time, being built on boundary conditions, the criteria outline a vision of successful sustainable PSS, thus addressing sustainability strategically. Therefore, by combining the definition and the list of criteria, PSS designers can target in the design all those factors that need to be considered to generate a sustainable PSS solution.

However, due to the limited time frame for this thesis, only a few interviews were conducted. Therefore, the business perspective can be further amplified through additional interviews or tailored for specific industry and type of PSS. Although this thesis points out the design criteria designers should adopt to develop sustainable PSS, it lacks guidelines on how businesses should practically address those criteria. By solving this gap, sustainability could be fully and strategically integrated in companies' operations. Those guidelines could be potentially be developed also allowing trade-off analysis between different PSS alternatives, thus leading companies in realizing the "most sustainable" PSS. Finally, due to the scope of the FSSD, an additional framework assessing economic sustainability could be integrated to this research.

References

Abramovici, Michael, Youssef Aidi, Akamitl Quezada, and Thomas Schindler. 2014. "PSS Sustainability Assessment and Monitoring Framework (PSS-SAM)–Case Study of a Multi-Module PSS Solution." *Procedia CIRP* 16: 140–45.

Allen, Mike. 2017. "Search Engines for a Literature Search." In *The SAGE Encyclopedia of Communication Research Methods*, edited by Allen Mike, 1574-1577. Thousand Oaks: SAGE Publications.

Annarelli, Alessandro, Cinzia Battistella, and Fabio Nonino. 2016. "Product Service System: A Conceptual Framework from a Systematic Review." *Journal of Cleaner Production* 139 (December): 1011–32. https://doi.org/10.1016/j.jclepro.2016.08.061.

Austin, Zubin, and Jane Sutton. 2014. "Qualitative Research: Getting Started." *The Canadian Journal of Hospital Pharmacy* 67 (6): 436–40.

Baines, Tim S., Howard W. Lightfoot, Steve Evans, Andy Neely, Richard Greenough, Joe Peppard, Rajkumar Roy, Essam Shehab, Ashley Braganza, and Ashutosh Tiwari. 2007. "State-of-the-Art in Product-Service Systems." *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture* 221 (10): 1543–52. https://doi.org/10.1243/09544054JEM858

Barquet, Ana Paula, Johannes Seidel, Günther Seliger, and Holger Kohl. 2016. "Sustainability Factors for PSS Business Models." *Procedia CIRP* 47: 436–41. https://doi.org/10.1016/j.procir.2016.03.021

Baumgartner, Rupert J., and Jouni Korhonen. 2010. "Strategic Thinking for Sustainable Development". *Sustainable Development* 18 (2010): 71-75. https://doi.org/10.1002/sd.452.

Bazeley, Patricia. 2013. *Qualitative Data Analysis: Practical Strategies*. Sage.

Bhamra, Tracy, Ricardo J. Hernandez, Yaone Rapitsenyane, and Rhoda Trimingham. 2018. "Product Service Systems: A Sustainable Design Strategy for SMEs in the Textiles and Leather Sectors." *She Ji: The Journal of Design, Economics, and Innovation* 4 (3): 229–48. https://doi.org/10.1016/j.sheji.2018.07.001.

Booth, Andrew, Anthea Sutton, and Diana Papaioannou. 2016. *Systematic Approaches to a Successful Literature Review*. Sage.

Brian, Keeley. 2015. *OECD Insights Income Inequality The Gap between Rich and Poor: The Gap between Rich and Poor*. oecd Publishing. https://doi.org/10.1787/19936753

Broman, Göran, and Karl-Henrik Robèrt. 2017. "A Framework for Strategic Sustainable Development." *Journal of Cleaner Production* 140: 17–31. https://doi.org/10.1016/j.jclepro.2015.10.121

Brundtland, Gro. 1987. *Our common future: The World Commission on Environmental and Development.* Oxford: Oxford university Press.

BusinessDictionary. n.d. "Stakeholders." Accessed May 27, 2019. http://www.businessdictionary.com/definition/stakeholder.html

BusinessDictionary. n.d. "Value creation." Accessed May 28, 2019. http://www.businessdictionary.com/definition/value-creation.html

Byggeth, Sophie, and Elisabeth Hochschorner. 2006. "Handling Trade-Offs in Ecodesign Tools for Sustainable Product Development and Procurement." *Journal of Cleaner Production* 14 (15–16): 1420–30. https://doi.org/10.1016/j.jclepro.2005.03.024.

Cambridge Dictionary. n.d. "Holistic." Accessed May 28, 2019. https://dictionary.cambridge.org/dictionary/english/holistic.

Ceschin, Fabrizio. 2014. "Introducing and Scaling Up Sustainable Product-Service Systems: Insights from Transition Studies." In *Sustainable Product-Service Systems*, edited by Ceschin Fabrizio, 41–80. Cham: Springer International Publishing.

Chen, Chong-Wen. 2018. "Guidance on the Conceptual Design of Sustainable Product–Service Systems." *Sustainability* 10(7): 2452. https://doi.org/10.3390/su10072452.

Chen, Dongping, Xuening Chu, Xiaoyang Yang, Xiwu Sun, Yupeng Li, and Yuliang Su. 2015. "PSS solution evaluation considering sustainability under hybrid uncertain environments." *Expert Systems with Applications* 42(14): 5822-38. https://doi.org/10.1016/j.eswa.2015.04.003

Chierici, Elisabetta, and Giacomo Copani. 2016. "Remanufacturing with Upgrade PSS for New Sustainable Business Models." *Procedia CIRP* 47: 531-536. https://doi.org/10.1016/j.procir.2016.03.055

Chou, Chun-Juei, Chong-Wen Chen, and Chris Conley. 2015. "An Approach to Assessing Sustainable Product-Service Systems." *Journal of Cleaner Production* 86: 277–84. https://doi.org/10.1016/j.jclepro.2014.08.059

Claessens, Maximilian. 2015. "DEFINITION OF PRODUCT AND SERVICE – WHAT IS A PRODUCT, WHAT IS A SERVICE?." Marketing-Insider - Principles of Marketing explained. April 23, 2015. https://marketing-insider.eu/definition-of-product/.

Dreyer, Louise, Michael Hauschild, and Jens Schierbeck. 2006. "A Framework for Social Life Cycle Impact Assessment (10 Pp)." *The International Journal of Life Cycle Assessment* 11 (2): 88–97.

Dijkman, Teunis J., Jan-Markus Rödger, and Niki Bey. 2015. 'How to Assess Sustainability in Automated Manufacturing'. In *2015 IEEE International Conference on Automation Science and Engineering (CASE)*, 1351–1356. IEEE. https://doi.org/10.1109/CoASE.2015.7294286

Ellger, Christof, and Joachim Scheiner. 1997. “After Industrial Society: Service Society as Clean Society? Environmental Consequences of Increasing Service Interaction.” *Service Industries Journal* 17 (4): 564–79. https://doi.org/10.1080/02642069700000035

Fernandez-Feijoo, Belen, Silvia Romero, and Silvia Ruiz. 2014. “Effect of Stakeholders’ Pressure on Transparency of Sustainability Reports within the GRI Framework.” *Journal of Business Ethics* 122 (1): 53–63.
França, César L., Goran Broman, Karl-Henrik Robert, George Basile, and Louise Trygg. 2017. An approach to business model innovation for strategic sustainable development. *Journal of Cleaner Production* 140 (2017): 155-166. http://dx.doi.org/10.1016/j.jclepro.2016.06.124.

Gough, David, Sandy Oliver, and James Thomas. 2017. *An Introduction to Systematic Reviews*. Sage.

Graedel, Thomas E. 1997. “Life-cycle Assessment in the Service Industries.” *Journal of Industrial Ecology* 1 (4): 57–70. https://doi.org/10.1162/jiec.1997.1.4.57

Haase, Ronja P., Daniela C. A. Pigosso, and Tim C. McAloone. 2017. “Product/Service-System Origins and Trajectories: A Systematic Literature Review of PSS Definitions and Their Characteristics.” *Procedia CIRP* 64: 157–62. https://doi.org/10.1016/j.procir.2017.03.053

Harrell, Margaret C., and Melissa A. Bradley. 2009. *Data collection methods. Semi-structured interviews and focus groups*. Rand National Defense Research Inst santa monica ca.

Hobson, Kersty, N. Lynch, Debra Lilley, and Grace Smalley. 2018. “Systems of Practice and the Circular Economy: Transforming Mobile Phone Product Service Systems.” *Environmental Innovation and Societal Transitions* 26: 147–57. https://doi.org/10.1016/j.eist.2017.04.002.

Hu, H. Allen, Sheng Hung Chen, Chia Wei Hsu, Chenlan Wang. 2012. “Development of Sustainability Evaluation Model for Implementing Product Service Systems.” International Journal of Environmental Science and Technology 9 (2): 343–54. https://doi.org/10.1007/s13762-012-0037-7.

Johnson, Nicholas L. 2017. “Platform vs. Linear: Business Models 101.” *APPLICO*. March 30, 2017. https://www.applicoinc.com/blog/platform-vs-linear-business-models-101/.

Kim, Kwang-Jae, Chie-Hyeon Lim, Jun-Yeon Heo, Dong-Hee Lee, Yoo-Suk Hong, and Kwangtae Park. 2016. “An Evaluation Scheme for Product–Service System Models: Development of Evaluation Criteria and Case Studies.” *Service Business* 10 (3): 507–30.

Kitchenham, Barbara. 2004. “Procedures for Performing Systematic Reviews.” *Keele, UK, Keele University* 33 (2004): 1–26.

Lee, Sora, Youngjung Geum, Hakyeon Lee, and Yongtae Park. 2012. “Dynamic and Multidimensional Measurement of Product-Service System (PSS) Sustainability: A Triple Bottom Line (TBL)-Based System Dynamics Approach.” *Journal of Cleaner Production* 32: 173–82. https://doi.org/10.1016/j.jclepro.2012.03.032

Lin, Ru-Jen, Kim-Hua Tan, and Yong Geng. 2013. "Market Demand, Green Product Innovation, and Firm Performance: Evidence from Vietnam Motorcycle Industry." *Journal of Cleaner Production* 40: 101–7. https://doi.org/10.1016/j.jclepro.2012.01.001.

Mallett, Richard, Jessica Hagen-Zanker, Rachel Slater, and Maren Duvendack. 2012. "The Benefits and Challenges of Using Systematic Reviews in International Development Research." *Journal of Development Effectiveness* 4 (3): 445–55. https://doi.org/10.1080/19439342.2012.711342

Manzini, Ezio, and Carlo Vezzoli. 2002. *Product-service systems and sustainability: Opportunities for sustainable solutions*. Paris: UNEP-United Nations Environment Programme.

Maxwell, Joseph A. 2012. Qualitative Research Design: *An Interactive Approach*. Sage.

Mills, Albert J., Gabrielle Durepos, and Elden Wiebe. 2012. "Coding: Open Coding." In *Encyclopedia of Case Study Research*, edited by Mills Albert J., Gabrielle Durepos, and Elden Wiebe, 155-157. Thousand Oaks: SAGE Publications.

Missimer, Merlina. 2015. "Social sustainability within the framework for strategic sustainable development." PhD diss., Blekinge Tekniska Högskola, Karlskrona.

Namey, Emily, Greg Guest, Lucy Thairu, and Laura Johnson. 2008. "Data Reduction Techniques for Large Qualitative Data Sets." *Handbook for Team-Based Qualitative Research* 2 (1): 137–61.

Negri, Elisa, Maria Holgado, Dirk Wagner, Christian Grefrath, Marco Macchi, and Gerhard Gudergan. 2016. "Continuous Improvement Planning through Sustainability Assessment of Product-Service Systems." *International Journal of Productivity and Quality Management* 18 (2/3): 168. https://doi.org/10.1504/IJPQM.2016.076706

Pádua Pieroni, Marina de, Caio Augusto Nunes Marques, Renato Nunes Moraes, Henrique Rozenfeld, and Aldo Roberto Ometto. 2017. "PSS Design Process Models: Are They Sustainability-Oriented?." *Procedia CIRP* 64: 67–72. https://doi.org/10.1016/j.procir.2017.03.040

Pigosso, Daniela Cristina Antelmi, Sabrina Rodrigues Sousa, Américo Guelere Filho, Aldo Roberto Ometto, and Henrique Rozenfeld. 2012. "Is the Industrial Product-Service System Really Sustainable?." In *Proceedings of the 2nd CIRP IPS2 Conference 2010; 14-15 April; Linköping; Sweden*, 59–65. Linköping University Electronic Press.

Robèrt, Karl-Henrik, Broman Göran, David Waldron, Henrik Ny, Sophie Hallstedt, David Cook, Lena Johansson, Jonas Oldmark, George Basile, Hördur Haraldsson, Jamie MacDonald, Brendan Moore, Tamara Connell, Merlina Missimer, Elaine Daly, and Pierre Johnson. 2018. *Strategic Leadership towards Sustainability*. Karlskrona: Psilanders grafiska.

Robèrt, Karl-Henrik, Broman Göran, David Waldron, Henrik Ny, Sophie Byggeth, David Cook, Lena Johansson, Jonas Oldmark, George Basile, Hördur Haraldsson, Jamie MacDonald,

Brendan Moore, Tamara Connell, Merlina Missimer, Pierre Johnson, and Elaine Daly. 2015. *Strategic Leadership towards Sustainability*. Karlskrona: Psilanders grafiska.

Robèrt Karl-Henrik, George Basile, Broman Göran, Sophie Byggeth, David Cook, Hördur Haraldsson, Lena Johansson, Jamie MacDonald, Henrik Ny, Jonas Oldmark, David Waldron, Brendan Moore, Tamara Connell, Merlina Missimer. 2010. *Strategic Leadership towards Sustainability*. Karlskrona: Psilanders grafiska.

Roy, Robin. 2000. "Sustainable Product-Service Systems." *Futures* 32 (3): 289–99. https://doi.org/10.1016/S0016-3287(99)00098-1.

Santana, Fabiana Soares, Claudio Barberato, and Antonio Mauro Saraiva. 2010. "A Reference Process to Design Information Systems for Sustainable Design Based on LCA, PSS, Social and Economic Aspects." In *What Kind of Information Society? Governance, Virtuality, Surveillance, Sustainability, Resilience*, edited by Jacques Berleur, Magda David Hercheui, and Lorenz M. Hilty, 269–80. IFIP Advances in Information and Communication Technology. Springer Berlin Heidelberg.

Savin-Baden, Maggi, and Claire Howell. Major. 2013. "Ethics and ethical approval." In *Qualitative Research: The essential guide to theory and practice.* edited by Savin-Baden, Maggi, and Claire Howell. Major, 319-337. New York: Routledge.

Slaper, Timothy F., and Tanya J. Hall. 2011. "The Triple Bottom Line: What Is It and How Does It Work." *Indiana Business Review* 86 (1): 4–8.

Sousa-Zomer, Thayla Tavares, and Paulo Augusto Cauchick Miguel. 2015. "Product-Service Systems as a Promising Approach to Sustainability: Exploring the Sustainable Aspects of a PSS in Brazil." *Procedia CIRP* 30: 138–43. https://doi.org/10.1016/j.procir.2015.02.025

Sousa-Zomer, Thayla Tavares, and Paulo Augusto Cauchick Miguel. 2016. "Exploring the Consumption Side of Sustainable Product-Service Systems (PSS): An Empirical Study and Insights for PSS Sustainable Design." *CIRP Journal of Manufacturing Science and Technology* 15: 74–81. https://doi.org/10.1016/j.cirpj.2016.04.004

Sousa-Zomer, Thayla Tavares, and Paulo Augusto Cauchick Miguel. 2017. "Proposal of a Hotspot-Based Approach to Identifying Social Impacts along the Product-Service Systems Life Cycle in the Early Design Phases." *Procedia CIRP* 64: 85–90. https://doi.org/10.1016/j.procir.2017.03.060

Steffen, Will, Wendy Broadgate, Lisa Deutsch, Owen Gaffney, and Cornelia Ludwig. 2015. "The Trajectory of the Anthropocene: The Great Acceleration." *The Anthropocene Review* 2 (1): 81–98. https://doi.org/10.1177/2053019614564785.

Sundin, Erik, Elin Nässlander, and Alan Lelah. 2015. "Sustainability Indicators for Small and Medium-Sized Enterprises (SMEs) in the Transition to Provide Product-Service Systems (PSS)." *Procedia CIRP* 30: 149–54. https://doi.org/10.1016/j.procir.2015.02.155

Thomas, David R. 2006. “A General Inductive Approach for Analyzing Qualitative Evaluation Data.” *American Journal of Evaluation* 27 (2): 237–46. https://doi.org/10.1177/1098214005283748.

Tsahalis, Jason, Vassilios C. Moussas, and Harry T. Tsahalis. 2012. “Towards a Holistic Optimization of Production Sustainability: A Multi-Level Approach.” In *Proceedings of the 5th International Conference from Scientific Computing to Computational Engineering, 5th IC-SCCE, Athens*, 4–7.

Tukker, Arnold. 2004. “Eight Types of Product–Service System: Eight Ways to Sustainability? Experiences from SusProNet.” *Business Strategy and the Environment* 13 (4): 246–260.

Tukker, Arnold, and Ursula Tischner. 2006. *New Business for Old Europe: Product-Service Development, Competitiveness and Sustainability*. Routledge.

United Nations. 2013. *World economic and social survey 2013: Sustainable development challenges*. New York: United Nations Publication.

Vezzoli, Carlo, Cindy Kohtala, Amrit Srinivasan, Liu Xin, Moi Fusakul, Deepta Sateesh, and Jan Carel Diehl. 2014. *Product-Service System Design for Sustainability*. 1 edition. Sheffield: Routledge.

Vezzoli, Carlo, Cindy Kohtala, Amrit Srinivasan, Liu Xin, Moi Fusakul, Deepta Sateesh, and J. C. Diehl. 2017. *Product-Service System Design for Sustainability*. Routledge. https://doi.org/10.4324/9781351278003

Vezzoli, Carlo, Fabrizio Ceschin, Jan Carel Diehl, and Cindy Kohtala. 2015. “New Design Challenges to Widely Implement ‘Sustainable Product–Service Systems.” *Journal of Cleaner Production* 97: 1–12. https://doi.org/10.1016/j.jclepro.2015.02.061

Vezzoli, Carlo, Fabrizio Ceschin, Lilac Osanjo, Mugendi K. M’Rithaa, Richie Moalosi, Venny Nakazibwe, and Jan Carel Diehl. 2018. “Sustainable Product-Service System (S.PSS).” In *Designing Sustainable Energy for All: Sustainable Product-Service System Design Applied to Distributed Renewable Energy*, edited by Vezzoli Carlo, Fabrizio Ceschin, Lilac Osanjo, Mugendi K. M’Rithaa, Richie Moalosi, Venny Nakazibwe, and Jan Carel Diehl, 41–51. Green Energy and Technology. Cham: Springer International Publishing.

Voss, Chris. 2010. “Case Research in Operations Management.” In *Researching Operations Management*, 176–209. Routledge.

Waage, Sissel A. 2007. “Re-Considering Product Design: A Practical ‘Road-Map’ for Integration of Sustainability Issues.” *Journal of Cleaner Production 15* (7): 638–49. https://doi.org/10.1016/j.jclepro.2005.11.026.

Wever, Renee, and Joost Vogtländer. 2021. “Design for the Value of Sustainability.” In *Handbook of Ethics, Values, and Technological Design: Sources, Theory, Values and Application Domains*, edited by Jeroen van den Hoven, Pieter E. Vermaas, and Ibo van de Poel, 1–31. Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-94-007-6994-6_20-1.

Williams, Amanda, Steve Kennedy, Felix Philipp, and Gail Whiteman. 2017. “Systems Thinking: A Review of Sustainability Management Research.” *Journal of Cleaner Production* 148: 866–81. https://doi.org/10.1016/j.jclepro.2017.02.002.

Willard, Bob. 2010. “3 Sustainability Models.” Sustainability Advantage. July 20, 2010. https://sustainabilityadvantage.com/2010/07/20/3-sustainability-models/.

Willard, Bob. 2012. *The New Sustainability Advantage: Seven Business Case Benefits of a Triple Bottom Line*. New Society Publishers.

Xing, Ke, Hsiao Fan Wang, and Wei Qian. 2013. “A Sustainability-Oriented Multi-Dimensional Value Assessment Model for Product-Service Development.” *International Journal of Production Research* 51 (19): 5908–33. https://doi.org/10.1080/00207543.2013.810349

Appendix A: Matrix for literature Analysis (System level)

Article name	Year	Author	Sustainability Model (e.g. triple-bottom-line)	Definition of Sustainable PSS emerging from the article	Internal /External	Type specific	Ind. specific	Int. Stake	Ext. Stake	Life Cycle
Designing Sustainable Energy for All	2018	Carlo Vezzoli, Fabrizio Ceschin, Lilac Osanjo, Mugendi K. M'Rithaa, Richie Moalosi, Venny Nakazibwe, Jan Carel Diehl	Three pillars of sustainability, the economic with the environmental and the socio-ethical ones (similar to the triple-bottom-line)	S.PSS (Sustainable Product-Service System) is an offer model providing an integrated mix of products and services that are together able to fulfil a particular customer demand (to deliver a "unit of satisfaction"), based on innovative interactions between the stakeholders of the value production system (satisfaction system), where the ownership of the product/s and/or its life cycle responsibilities remain by the provider/s, so that the economic interest of the providers continuously seek new environmentally and/or socio-ethically beneficial solutions	Internal (re-arranged the 2014 definition)	N	N	Y	Y	Y
Product-Service System Design for Sustainability	2014	Carlo Vezzoli, Cindy Kohtala and Amrit Srinivasan	Three pillars of sustainability, the economic with the environmental and the socio-ethical ones (similar to the triple-bottom-line)	An eco-efficient PSS is an offer model providing an integrated mix of products and services that are together able to fulfil a particular customer demand (to deliver a 'unit of satisfaction') based on innovative interactions between the stakeholders of the value production system (satisfaction system), where the economic and competitive interest of the providers continuously seeks environmentally beneficial new solutions.	Internal	N	N	Y	Y	N (value chain not life cycle)
New Business for Old Europe: Product-Service Development: Competitiveness and Sustainability	2006	Arnold Tukker and Ursula Tischner	Economy, Environment and Social considerations	Sustainability is not an automatic mechanism built into the PSS concept, but it depends on many conditions. A "sustainable" PSS is achievable only if sustainability considerations are integrated into all the steps of a PSS development and design process, that its market launch is carefully prepared in order to be successful, and finally that the solution on the market is reviewed relating to economic, environmental and social impacts. A "sustainable" PSS decouples economic growth from negative environmental impacts reaching the Factor X.	Internal	Only a kind of result-oriented	N	Y	Y	Y
A sustainability-oriented multi-dimensional value assessment model for product-service development	2013	K. Xing, H.-F. Wang and W. Qian	Cradle-to-grave perspective. Every company has an environmental impact through their products. Economic aspects regarding PSS value are considered.	No definition		Product-oriented	N	Y	N	Y
Design for the value of sustainability	2015	Wever R., Vogtländer J.	Triple-bottom-line	A sustainable PSS (SusPSS) consists of an integration of services to a low eco-cost product, thus increasing its value/production costs ratio. Eco-costs are virtual costs representing the eco-burden of a product or service, with the understanding that eco-costs may well become real costs in the future through legislation internalizing this burden.	Internal	N	N	Y	Y	N

Sustainability indicators for small and medium-sized enterprises (SMEs) in the transition to provide Product-Service Systems (PSS)	2015	Sundin E., Näsländer E., Lelah A.	Triple-bottom-line	No definition		N	N	Y	N	Y
Exploring the consumption side of sustainable product-service systems (PSS): An empirical study and insights for PSS sustainable design	2016	Sousa Zomer T.T., Cauchick Miguel P.A	Triple-bottom-line	A sustainable PSS is a eco-efficient PSS sustainable on both the supply side (before the consumption) and the consuption side. In order to integrate the consuption side, social practices must be taken into consideration.	Emerging from the article	N	N	Y	Y	Y
Proposal of a Hotspot-based Approach to Identifying Social Impacts along the Product-Service Systems Life Cycle in the Early Design Phases	2017	Sousa Zomer T.T., Cauchick-Miguel P.A.	Triple-bottom-line	To be considered as a real sustainable solution, a PSS should provide environmental, economic, and social benefits throughout the whole life cycle.	Based on external sources	N	N	Y	Y	Y
Product-service systems as a promising approach to sustainability: Exploring the sustainable aspects of a PSS in Brazil	2015	Sousa Zomer T.T., Cauchick Miguel P.A.	Triple-bottom-line	No definition		N	N	Y	Y	Y
A reference process to design information systems for sustainable design based on LCA, PSS, social and economic aspects	2010	Santana F.S., Barberato C., Saraiva A.M.	Economy, Environment and Social considerations	PSS is considered as a tool to enhance environmental sustainability. It must be integrated with both LCA and social and economic criteria in order to achieve a full sustainability.	Internal	N	N	Y	Y	Y
Continuous improvement planning through sustainability assessment of product-service systems	2016	Elisa Negri, Maria Holgado, Dirk Wagner, Christian Grefrath, Marco Macchi, Gerhard Gudergan	Triple Bottom Line + SD (Sustainable development)	No definition		N	N	Y	Y	Y
Sustainable product-service systems	2000	Robin Roy	Environmental perspective	Sustainable product-service systems are models designed and marketed to provide customers with a particular result or function without them necessarily having to own or buy physical products in order to get that result. In addition the design of new product-service systems may involve the development or use of ‘eco-efficient’ products that are more efficient in their use of energy and materials and generate less pollution and waste.	Internal	N	N	Y	N	N
PSS Sustainability Assessment and Monitoring framework (PSS-SAM) - Case study of a multi-module PSS Solution.	2014	Abramovici M, Aidi Y, Quezada A, Schindler	Triple-bottom-line	No definition		N	N	Y	Y	Y

Sustainability Factors for PSS Business Models	2016	Ana Paula Bezerra Barquet,Johannes Seidel,Holger Kohl	Triple-bottom-line	No definition		N	N	Y	Y	Y
An approach to assessing sustainable product-service systems	2015	Chun-Juei Chou, Chong-Wen Chen, Chris Conley	The concept of sustainability is built on the Eco-efficiency index, which is expressed through the ratio Product-service value/Sustainability impact. The sustianbaility impact is considered in environmental, social and economic terms.	A sustainable PSS means that product-service solutions should generate satisfactory value for customers and fulfill the sustainability requirements at the same time.	Internal	N	N	Y	Y	Y
Sustainable Product-Service Systems. Between Strategic Design and Transition Studies	2014	Fabrizio Ceschin	PSS related to other Sustainability concepts: natural capitalism, cradle to cradle and systematic design	A sustainable PSS can be defined as a PSS where the economic and competitive interest of the providers continuously seeks environmentally beneficial new solutions, while maximising social well-being, equity and cohesion.	Internal	N	N	Y	Y	N
Systems of practice and the Circular Economy: Transforming mobile phone product service systems	2018	Hobson K., Lynch N., Lilley D., Smalley G.	Circular Economy perspective	The concept of Sustainable Product Service Systems (SPSS) is about reconsidering how material and service needs are being and/or can be met, working towards goods and parallel services that are more environmentally benign and materially/energetically efficient.	Internal	N	N	Y	N	N
Development of sustainability evaluation model for implementing product service systems	2012	Hu H.A., Chen S.H., Hsu C.W., Wang C., Wu C.L.	tipple bottome line + additional considerations. Sustainability is divided into two dimensions: Product and Organization. The Product side considers the three dimensions of the triple-bottom-line. The organization side considers management capabilities and external factors.	No definition		N	N	Y	Y	N

An evaluation scheme for product–service system models: development of evaluation criteria and case studies	2016	Kim K.-J., Lim C.-H., Heo J.-Y., Lee D.-H., Hong Y.-S., Park K.	Triple-bottom-line	No definition		N	N	Y	Y	Y
Dynamic and multidimensional measurement of product-service system (PSS) sustainability: a triple bottom line (TBL)-based system dynamics approach	2012	Sora Lee, Youngjung Geum, Hakyeon Lee, Yongtae Park	Triple-bottom-line	Definition of PSS sustainability from the TBL perspective. A PSS is environmentally sustainable when 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. That PSS is socially sustainable when the PSS is sustainably and actively acceptable to socio improving public welfare without invalidating social justice. That PSS is economically sustainable when the PSS is sustainably operational, fulfilling the economic motivation of each stakeholder structurally.	Internal	N	N	Y	Y	N
Product service system: A conceptual framework from a systematic review	2016	Annarelli A., Battistella C., Nonino F.	Tripple bottom line approach	General definition of PSS (considered intrinsically sustiainable): PSS is 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.	Built on external literature	N	N	Y	Y	N
Product Service Systems: A Sustainable Design Strategy for SMEs in the Textiles and Leather Sectors	2018	Bhamra T., Hernandez R.J., Rapitsenyane Y., Trimingham R.	Environmental, social and economic perspectives	Sustainable PSS are part of a radical transformation of our economic system from a consumption model and a linear approach to production to one less dependent on physical resources (p.231). A sustainable PSS should also have environmental, social, and economic impact in ways that ensure sustainable living for all (p.232)	Built on external literature	result-oriented PSS is more likely to have greater sustainable impacts	N	Y	Y	Y
PSS solution evaluation considering sustainability under hybrid uncertain environments	2015	Chen D., Chu X., Yang X., Sun X., Li Y., Su Y.	Triple-bottom-line	No definition		N	N	Y	Y	N
Guidance on the Conceptual Design of Sustainable Product–Service Systems	2018	Chong-Wen Chen	Triple-bottom-line + SD (Sustainable development) (with integrating the institutional dimension)	A sustainable PSS is a offer model connecting value network between different stakeholders and integrating sustainability visions into the service context.	Emerging from the article	N	N	Y	Y	Y

Appendix B: Matrix for Literature Analysis (Success level)

Article name	Environmental criteria	Social criteria
Designing Sustainable Energy for All	1) Product ownership and/or the economic responsibility of its life cycle performance remains by the producer/ providers who are selling a unit of satisfaction rather than (only) the product. Depending on the kind of S.PSS: 2) Product lifespan extension and use intensification; 3) Material life extension (recycling, energy recovery, composting); 4) Resource (materials and energy) minimisation; 5) Resource (materials and energy) renewability and biocompatibility; 6) Resource (materials and energy) toxicity/harmfulness minimisation	Socioethical: social equity (justice/fairness) and cohesion (cooperation) potentials.
	Economic criteria	**Additional criteria**
	N	N
Article name	**Environmental criteria**	**Social criteria**
Product-Service System Design for Sustainability	1. System life optimisation (extending life and intensify the use) 2. Transportation/distribution reduction (of goods/semi-products/final products/ people) 3. Resource reduction (energy, material, natural resources) 4. Waste minimisation/valorisation 5. Conservation/biocompatibility 6. Toxicity reduction	1. Improve employment/working conditions 2. Improve equity and justice in relation with stakeholders 3. Enable responsible/sustainable consumption 4. Favour/integrate the weak and marginalised 5. Improve social cohesion 6. Empower/valorise local resources
	Economic criteria	**Additional criteria**
	N	N
Article name	**Evaluation criteria**	**Social criteria**
New Business for Old Europe: Product-Service Development. Competitiveness and Sustainability	1) System life optimization 2) mobility reduction 3) resources reduction 4) waste minimisation/valorisation 5) conservation/bio-compatibility	1) Possibility of customers consuming in a more socially responsible manner 2) health and safety (employees, customers, stakeholders) 3) living conditions/quality of life (customers'/users' perspective) 4) employment/working conditions 5) equity and justice/relation to stakeholders (society/global perspective) 6) Respect cultural diversity (society/local perspective)
	Economic criteria	**Additional criteria**
	1) Market position and competitiveness 2) profitability/added value for companies 3) added value for customers 4) long-term business development/risk (market risk/implementation issue/ROI) 5) partnership/co-operation 6) macro-economic effect	N

Article name	Environmental criteria	Social criteria
A sustainability-oriented multi-dimensional value assessment model for product-service development	1) Analysis of the energy and material flows pointing out the environmental loads (emissions, waste) and the relative 2) environmental impact (global warming, etc.). The 3) maintenance and the 4) upgrade are also included. Some other operations and activities (e.g. transportation, installation/de-installation using powered tools, cleaning/refurbishing, etc.) are not considered due to the small duration or quantity of their deployment.	N
	Economic criteria	**Additional criteria**
	N	N
Article name	**Environmental criteria**	**Social criteria**
Design for the value of sustainability	1) Reduce materials, 2) energy and 3) transportation while maintaining high value/production costs ratio	N
	Economic criteria	**Additional criteria**
	Value/production costs ratio	N
Article name	**Environmental criteria**	**Social criteria**
Sustainability indicators for small and medium-sized enterprises (SMEs) in the transition to provide Product-Service Systems (PSS)	This article focuses only on environmental sustainability aspects. The criteria related are: 1) Amount of transportation; 2) Amount of energy used; 3) Use of the equipment; 4) Quality of the product; 5) Lifetime of the product; 6) Amount of water used; 7) Amount of recycled material used; 8) Amount of materials used; 9) Amount of recuperation of waste; 10) Health; 11) Number of products being recycled at the end-of-life	N
	Economic criteria	**Additional criteria**
	N	N
Article name	**Environmental criteria**	**Social criteria**
Exploring the consumption side of sustainable product-service systems (PSS): An empirical study and insights for PSS sustainable design	N	N
	Economic criteria	**Additional criteria**
	N	N
Article name	**Environmental criteria**	**Social criteria**
Proposal of a Hotspot-based Approach to Identifying Social Impacts along the Product-Service Systems Life Cycle in the Early Design Phases	N	(i)Workers: 1) Health and Safety, 2) Hours of work; (ii) Consumers: 3) Health and Safety, 4) Feedback mechanisms, 5) End of life responsibility, 6) Knowledge transfer/awareness, 7) Income generation 8) Empowerment; (iii) Local Community: 9) Safe and healthy living conditions, 10) Access to material resources, 11) Access to immaterial resources, 12) Community engagement, 13) Local employment, 14) Cultural heritage, 15) Income generation, 16) Empowerment; (iv) Society: 17) Public commitment to sustainability issues, 18) Contribution to economic development, 19) Technology development, 20) Public policies; (v) Value chain actors: 21) Supplier relationships
	Economic criteria	**Additional criteria**
	N	N

Article name	Environmental criteria	Social criteria
Product-service systems as a promising approach to sustainability: Exploring the sustainable aspects of a PSS in Brazil	1) Greenhouse gases emissions; 2) Renewable resources use; 3) Efficient use of resources; 4) Waste generation; 5) Energy consumption; 6) Efficient use of transport;	1) Health and safety; 2) Employment of labour;
	Economic criteria	**Additional criteria**
	1) Added value; 2) Operational costs;	PSS acceptance
Article name	**Environmental criteria**	**Social criteria**
A reference process to design information systems for sustainable design based on LCA, PSS, social and economic aspects	Functionality conception: 1) Carefully study the consumer before replacing a product by a service, 2) Identify options for PSS and evaluate environmental impacts of both products and services, to choose the best alternative; (ii) Raw material acquisition: 3) Minimize the volume of materials, 4) Substitution of no/less hazardous raw materials, 5) Analyse the extraction and processing, 6) Minimize energy, water, emissions, wastes and eliminate toxic components, 7) Evaluate/reduce transport impact, 8) Eliminate or reduce non-renewables usage; (iii) Manufacturing: 9) Optimize production and technology, 10) Minimize energy, wastes, water, emissions and effluents, 11) Eliminate/minimize toxic components and non-biodegradable substances, 12) Maximise ecology efficiency; (iv) trade and delivery: 13) Evaluate/reduce transport impact for both product and services, 14) Evaluate volume and nature of transport, and the type of fuel usage, 15) Eliminate/reduce emissions to air and waste; (v) Use/maintenance: 16) Minimize energy, water, emissions to air, wastes (product and packing), and effluents, 17) Eliminate non-biodegradable substances, 18) Maximise durability; (vi) Re-use/Recycling/energy recovery/disposal: 19) Apply strategies to extend the product life cycle, 20) Design for repair and modular design, 21) Simplify recovery of components for reuse and for recycling or waste treatment/disposal	(i) Functionality conception: 1) Evaluate quality of physical and social life, 2) Verify the social impacts to replace a product for a service and vice-versa, 3) Evaluate dynamic (time) approach; (ii) Raw material acquisition: 4) Verify where and how do the raw materials are extracted/processed; 5) Verify the ownership rights, 6) Verify if the trading arrangements are equitable (iii) Manufacturing plus (iv) Trade and delivery: 7) Analyse the employee conditions of work (at company or subcontracted companies) and impacts on local community, 8) Analyse local investments and adverse impacts for local and global community, 9) Evaluate local initiatives; (v) Use/maintenance: 10) Analyse adverse health/safety impacts for local and global community; (vi) Re-use/Recycling/energy recovery/disposal: 11) Analyse adverse health/safety impacts for local and the global community
	Economic criteria	**Additional criteria**
	To be applied to all the life cycle phases: 1) Verify if the PSS is cost effective, 2) Verify the cost of the PSS when compared to a competing versions of a product or a service able to meet the same requirements, 3) Consider the environmental external costs (e.g. end of life, recovery, reuse, treatment, disposal), 4) Evaluate distributed economic model, with local resource supply (creative communities/cooperative networks)	Functionality conception: 1) Verify legal aspects to the product introduction, 2) Innovation of the life cycle basis, 3) Platforms to implement PSS (ii) Raw material acquisition plus (iii) Manufacturing: 4) Stakeholder reconfiguration, 5) Identification of new research areas and professional competence, 6) Compliance with legal and technical specifications, 7) Evaluate quality aspects; (iv) trade and delivery: 8) Stakeholder reconfiguration; (v) Use/maintenance: 9) evaluate rebound effects, 10) Prevent colateral effects to PSS introduction

Article name	Environmental criteria	Social criteria
Continuous improvement planning through sustainability assessment of product-service systems	The environmental analysis considers those material and energy flows crossing system boundaries, both as 1) inputs (resource consumption in terms of abiotic materials/biotic materils/ water/soil erosion/air) or as 2) outputs (emissions in terms of acidification/global warming/ozone depletion/eutrophication/eco-toxicity/human toxicity/Photochemical Oxidant Formation/PAN creation/waste). The levels of 3) recyclability and 4) disassemblbility are also considered.	The social analysis considers the impacts on people due to the PSS in its life cycle, regardless of whether they are internal (employee, customers suppliers) or external (local community). 3 classes of indicators: A) fundamental issues (1) such as child labour, 2) forced labor, 3) health and safety of employees, 4) corruption, 5) respect for law, 6) degrading treatments, 7) religion and 8) opinion freedom) B) indicators referring to the Service Unit (9) social issues that may impact satisfaction and productivity of workers, 10) reduce waste generation and resource consumption, and affect company's costs and profits) C) behavior of the company regarding various current social issues (such as 11) gender discrimination, 12) minorities discrimination, 13) age discrimination, 14) job creation for disabled, 15) choice of sustainability committed partners, etc.)
	Economic criteria	**Additional criteria**
	The economic analysis also concerns the financial flows that are internal to the system, because what is a cost for a player can be a revenue for another; the economic dimension receives a multiple assessment, by keeping the perspectives of each actor separated. how the service may be priced is obtained through monitoring how the user's costs decrease, in order to grant economic sustainability both for the PSS solution provider and for the user.	N
Article name	**Environmental criteria**	**Social criteria**
Sustainable product-service systems	N	N
	Economic criteria	**Additional criteria**
	N	N
Article name	**Environmental criteria**	**Social criteria**
PSS Sustainability Assessment and Monitoring framework (PSS-SAM) - Case study of a multi-module PSS Solution	A Key sustianability indicator (KSI) has been defined to assess the performance of a PSS in the environmental sustainability domain. PSS environmental performance: this indicator describes the fulfillment of ecological critera of PSS products throught entire lifecycle. Criteria affecting this indicator are: 1) demand of energy, 2) water, 3) materials, 4) extent of emissions, 5) percentage of recycled materials.	A Key sustianability indicator (KSI) has been defined to assess the performance of a PSS in the social sustainability domain. PSS social performance: 1) Number of training activites, 2) degree of satisfaction of employees, 3) cusomter, 4) suppliers, 5) health and safety prevention, 6) the percentage of accidents, 7) job creation.
	Economic criteria	**Additional criteria**
	A Key sustainability indicator (KSI) has been defined to assess the performance of a PSS in the economic sustainability domain. PSS economic performance: this indicator helps to control the economic aspects cumulated throughout the entire lifecycle of a PSS product. The criteria affecting this indicator are: 1) added value, 2) gross profit, 3) sales growth, 4) return on sales, 5) return on equity, 6) the cost of PSS development, 7) the cost of service processes, 8) the costs of infrastructure and 9) spare parts.	A Key sustainability indicator (KSI) has been defined to assess the performance of a PSS. PSS specific performance: this indicator provides an assessment of PSS-specific values. The criteria affecting this indicator are: 1) Order cycle time, 2) reuse of goods, 3) number of new customers.

Article name	Environmental criteria	Social criteria
Sustainability Factors for PSS Business Models	Factor 1 – Design for Environment (DFE): 1) Minimize material consumption and select low-impact materials; 2) Minimize energy consumption and select systems with energy-efficient operation stage; 3) Minimize toxic emissions and select harmless materials; 4) Apply principles of optimization of product lifespan (Apply principles of design for disassembly and optimization of product lifespan, which covers the design of appropriate lifespan and design for reliability. Also actions to facilitate upgrading, maintenance and adaptability and design for end of life strategies, such as repairs, reuse and remanufacture, should be taken into account)	Factor 3. Promote behavior change: 1) Educate customers; 2) Involve customers in the development; 3) Increase customer satisfaction./// Factor 4 - Delineate actions to social well-being: 4) Increase and maintain jobs; 5) Dissemination of skills ((As PSSs are more labour and relationship oriented, the increase in local employment can also lead to dissemination of skills. An example are the skills and knowledge required to provide services and support the product)); 6) Broaden access to goods and services; 7) Regenerate and empower local economies((for example, respecting local cultural characteristics and favouring local-based enterprises or initiatives)); 8) Integrate people ((No unemployed, minority or marginalized social group was included as players of the business model))
	Economic criteria	**Additional criteria**
	Factor 2- Identify economic value for each stakeholder: 1) Cost savings result from reduced quantities of materials; 2) Economic incentive to recover products (As the product ownership and responsibility belongs to the PSS provider, they will have easy access to the product in end of life); 3) Increased range of services	Factor 5. Innovate in different levels: 1) Product and service innovation; 2) Value chain innovation (interactive with stakeholders and the convergence of their interests, it has a lower overall cost and higher gains.); 3) Technology innovation
Article name	**Environmental criteria**	**Social criteria**
An approach to assessing sustainable product-service systems	Sustainable product-service efficiency = Product-service value/ Sustainability impact. In the Sustainability Impact the Environment is considered through the impact on resources. The criteria are: in use phase impact (customer perspective): 1) life cycle of tangibles (e.g. Life cycle of products, Life cycle of physical facilities), 2) energy & water consumption, 3) waste generation & emissions; in the manufacturing phase (Company impact): 4) materials consumption, 5) energy&water consumption, 6) waste generation& emissions.	Sustainable product-service efficiency = Product-service value/ Sustainability impact. In the Sustainability Impact the Society is considered through the impact on people. The criteria are: in the use phase (Customer impact) : 1) safety&health, 2) cultural/institutional conflicts(e.g. Number of incidents of cultural/institutional conflicts); in the manufacturing phase (Company impact): 3) occupational satefy&health, 4) working time, 5) strucuture of employees (e.g.Reasonable ratio of male employees to female employees)
	Economic criteria	**Additional criteria**
	Sustainable product-service efficiency = Product-service value/ Sustainability impact. In the Sustainability Impact the Economy is considered through the impact on finance. The criteria are: in the use phase (Customter impact): 1) Payment of PSS offerings (e.g.Total customer cost of PSS solutions); in the manufacturing phase (Company impact): 2) Total cost of PSS project (e.g. Labor cost of services)	N
Article name	**Environmental criteria**	**Social criteria**
Sustainable Product-Service Systems. Between Strategic Design and Transition Studies	N	N
	Economic criteria	**Additional criteria**
	N	N

Article name	Environmental criteria	Social criteria
Systems of practice and the Circular Economy: Transforming mobile phone product service systems	N	N
	Economic criteria	**Additional criteria**
	N	N
Article name	**Environmental criteria**	**Social criteria**
Development of sustainability evaluation model for implementing product service systems	1) Energy consumption, 2) Ease of disassembly, 3) De-materialization and recyclability, 4) Hazardous material, 5) Emissions of pollutants.	1) Consumer acceptance, 2) Fairness and justice, 3) Healthy and safety, 4) Empowerment of stakeholders, 5) Sustainable consumption, 6) Improving life's quality, 7) Job creation
	Economic criteria	**Additional criteria**
	1) Price of the product, 2) Use time or frequency, 3) Added value, 4) Modularization, 5) Maintenance system, 6) Durability and longevity	In terms of Management capability: 1) Cash flow system, 2) Reasonable contracts, 3) Education, 4) Optimized transportation network, 5) Independent PSS department, 6) Product development and design, 7) Product development and design. In terms of External factors: 8) Brand advantage, 9) Innovative marketing model, 10) Product duplicability and immutability, 11) Synergy of the supply chain, 12) Reverse logistics, 13) Cross-sector cooperation, 14) Regulations.
Article name	**Environmental criteria**	**Social criteria**
An evaluation scheme for product–service system models: development of evaluation criteria and case studies	Planet: 1) Emissions of toxic substances; 2) Environmental management; 3) Capability of employees; 4) Profit sharing; 5) Working environment	People: Employment equity (1) Reducing layoffs, 2) Hiring temporary employees or apprentices, 3) Hiring female employees, 4) Abstaining from exploitation of child labor, 5) Hiring senior employees, 6) Hiring disabled employees, 7) Improving labor conditions for foreign employees, 8) Reducing/stopping workplace violence and sexual harassment); Acceptability (9)Employee acceptance, 10) Social acceptance, 11) Legal acceptance); Influence on society (12) Expanding employment opportunities, 13) Improve quality of life of stakeholders, 14) Contributing to local community, 15) Promoting eco-friendly consumption culture, 16) Contributing to global society, 17) Promoting cultural diversity)
	Economic criteria	**Additional criteria**
	Profitability which is assessed through the following criteria: 1) Fixed cost; 2) Operational cost; 3) Revenue; 4) Ecosystem structure; 5) Macroeconomic effects (Ripple effects resulting from PSS); 6) Product usage; 7) Material usage; 8) Energy usage	N
Article name	**Environmental criteria**	**Social criteria**
Dynamic and multidimensional measurement of product-service system (PSS) sustainability: a triple bottom-line (TBL)-based system dynamics approach	1) reduction of energy vs product, 2) reduction of air pollution emissions vs product	1) human health status; 2) improve social welfare
	Economic criteria	**Additional criteria**
	1) budget reduction of the local government, 2) profitability of each stakeholder	N

Article name	Environmental criteria	Social criteria
Product service system: A conceptual framework from a systematic review	N	N
	Economic criteria	**Additional criteria**
	N	N
Article name	**Environmental criteria**	**Social criteria**
Product Service Systems: A Sustainable Design Strategy for SMEs in the Textiles and Leather Sectors	N	N
	Economic criteria	**Additional criteria**
	N	N
Article name	**Environmental criteria**	**Social criteria**
PSS solution evaluation considering sustainability under hybrid uncertain environments	1) provide the capability to replenish environmental resources, 2) mitigate product consumption of environmental resources, 3) inspire people to behave responsibly towards the environment	1) provide the capability to improve quality of life, 2) inspire people to promote the communication, 3) relieves the internal employment pressure
	Economic criteria	**Additional criteria**
	1) establish a close and long-term relationship with customers	N
Article name	**Environmental criteria**	**Social criteria**
Guidance on the Conceptual Design of Sustainable Product–Service Systems	1) Life cycle management, 2) Material/resource reduction, 3) Energy efficiency, 4) Reduction in consumption.	1) Health/safety care, 2) Employee care, 3) Social and cultural change, 4) Welfare. .
	Economic criteria	**Additional criteria**
	N	Network building with stakeholders (1) Value co-creation, 2) Organizational change), customers (3) Customer perception, 4) Customer acceptance, 5) Customization, 6) Customer Involvement/ interaction) and institutions (7) Policy and regulation/ legislation, 8) Administration)

Appendix C: Matrix for Interview Analysis

Interview	Sustainability Model (e.g. triple-bottom-line)	Definition of Sustainable PSS	Internal /External	Int. Stake	Ext. Stake	Life Cycle	Additional aspects regarding Business Perspective	Environmental criteria	Social criteria	Economic criteria	Additional criteria
Interview 1	Triple-bottom-line	A sustainable PSS is a business model with integrating a holistic view that takes into account environmental, social and economic aspects in all the different phases of the life-cycle.	Internal	Y	Y	Y	- Take advantage of the technological innovation: integrate the technological advance within the industry in order to provide more successful, performant and sustainable PSS. - Connecting to customers and suppliers' systems and requirements, building long term relationships. From collaborations new technology innovations can emerge.	Reduced emissions (ideal goal zero emissions); limit use of natural resources; resource circularity; zero waste; landfill-free; material efficiency; choose or select the right kind of materials; eco-friendly use of the products; recycling and remanufacturing components of worn-out machines; refurbish machines to go into the second or third life; consider the correct life cycle impact in terms of transportation; not using acids, substances and chemicals that might be dangerous for peoples' health; energy optimization;	Health and safety of the operator; health, safety and wellbeing of the surrounding society; societal engagement; education training; occupational health and safety; fulfil all legal requirements;	Economically beneficial for all the stakeholders in the whole value chain	Having a code of conduct with customers and suppliers to ensure a shared understanding of environmental and social values thus extending sustainability throughout the whole PSS life-cycle. Ensure that customers are using the products in the right way without impacting negatively on the environment or on the society
Interview 2		PSS becomes sustainable if it takes the whole life cycle into account and optimize its production, for example by looking at the materials you use	Internal	Y	Y	Y	- Develop partnerships/collaborations: design the PSS in collaboration with both customers, to address better their needs, and suppliers, in order to develop new technologies together. - Integrate innovation inside the PSS, exploit the innovation regarding the industry.	Lower emissions; Material optimization; Product life-time extension; Reduction of the use of chemicals; increase the use of recycled materials; energy from renewable sources; materials from renewable sources;	Safety of employees; supplier social sustainability reliability; safety for the user;	Cheaper than the pure manufacturing/standard offering for both developers and customers;	
Interview 3	Sustainable Development Goals + Six areas of sustainability: 1) raw materials and resources 2) climate (emissions) 3) pure materials (toxicity) 4) social responsibility 5) reuse 6) ergonomics (customer care)	A sustainable PSS is a PSS circularly oriented, taking care of environmental and social issues along all the life cycle (loops).	Internal	Y	Y			Reduce the amount of materials; extend the life of the product; reduce the amount of emissions; reduction of chemicals; design in closed loops (recycling/remanufacturing);	Health and safety of the employees; health and safety of the subcontractors employees; healthy and inspired customers;	Effective maintenance/repair costs;	Digital flow of products: Track their information about maintenance operations, materials, warranties and second-hand market flow. To check if they can still meet the health and legal requirements as products even years after their production.

Appendix D: Economic Sustainability Criteria

PSS Economic sustainability criteria	References
Market position and competitiveness	Tukker and Tischner 2006
Profitability/added value for companies	Tukker and Tischner 2006
Added value (for customers, company)	Tukker and Tischner 2006; Sousa-Zomer and Cauchick-Miguel 2015; Abramovici et al. 2014
Long-term business development/risk (market risk/implementation issue/ROI)	Tukker and Tischner 2006
Value/ (production costs)	Wever and Vogtländer 2015
Operational costs	Sousa-Zomer and Cauchick-Miguel 2015; Abramovici et al. 2014
Verify if the PSS is cost effective	Santana, Barberato and Saraiva 2010
Verify the cost of the PSS when compared to a competing version of a product or a service able to meet the same requirements	Santana, Barberato and Saraiva 2010
Consider the environmental external costs (e.g. end of life, recovery, reuse, treatment, disposal)	Santana, Barberato and Saraiva 2010
Evaluate distributed economic model, with local resource supply (creative communities/cooperative networks)	Santana, Barberato and Saraiva 2010
User cost decrease	Negri et al. 2016
Gross profit	Abramovici et al. 2014
Sales growth	Abramovici et al. 2014
Return on sales	Abramovici et al. 2014
Return on equity	Abramovici et al. 2014
The cost of service processes	Abramovici et al. 2014
The costs of infrastructure and spare parts	Abramovici et al. 2014
Cost savings result from reduced quantities of materials	Barquet et al. 2016
Economic incentive to recover products (as the product ownership and responsibility belongs to the PSS provider, they will have easy access to the product in end of life)	Barquet et al. 2016
Increased range of services	Barquet et al. 2016
Payment of PSS offerings	Chou, Chen, and Conley 2015
Total production cost of PSS project	Chou, Chen, and Conley 2015
Price of the product	Allen Hu et al. 2012
Fixed cost	Kim et al. 2016
Operational cost	Kim et al. 2016
Revenue	Kim et al. 2016
Ecosystem structure	Kim et al. 2016
Macroeconomic effects (effects Ripple effects resulting from PSS)	Kim et al. 2016
Budget reduction of the local government	Lee et al. 2012
Profitability of each stakeholder	Lee et al. 2012

Appendix E: Concept table for database String development

Key concept	PSS	Sustainability	Design	Other
Synonyms	Product-service system	Servitisation (remember the Z)	Integration of products and services	Functional product
	Complex product system	Integrated solutions	Sustainable development	Green operation
	Sustainable solution	Design stage	Product design	Design process
Related terms	PSS-characteristics	PSS framework	ECO-PSS	Sustainability product-service system
	PSS obstacles	PSS business model	Business model	PSS-Design
	Sustainable PSS	Circular economy	Sustainability principles	Sustainable evaluation criteria
	Social factor	Social issue	Environmental aspect	Environmental issue
	Sustainability factors	Sustainability criteria	Environmental impact	Environmental effect
	Social impact	Social effect	Social aspect	Sustainable evaluation
		Environmental factors	Sustainable evaluation model	Sustainable business model
	Sustainable Assessment	Environmental value	Social value	Sustainable design strategies
	Life-Cycle design	Functional thinking	Strategic design	Design thinking
	Comprehensive design	Design for sustainability	new design	Competitive advantage
	definition	Customer acceptance	industrial	Process model
	innovation	System innovation	Strategic innovation	Solution evaluation
	Decision making	Business model		

Appendix F: Interview questions for the semi-structured interview

1) ***Can you give us an introduction to your company?*** *Subquestion/ alternative question: What is the main business of your company?*
2) ***What's your role inside the company?***
3) ***Can you describe what type of PSS-offerings you have?***
   Sub-Question/ alternative questions:
   Amongst your offerings we know you have a PSS-solution.
   What is a PSS-solution for your company?
   Can you describe us one of you PSS offerings? How does it work? How does your PSS look like?
4) ***Why have you decided to offer this kind of solution?***
   Sub-Question: *Which are the benefits that led you in shifting to PSS?*
5) ***Have you been involved in the design of the PSS-solution?***
   Sub-Question: *Where have you been in touch with PSS and how?*
6) ***Which aspects/ factors were important when you designed the PSS? What were the things that had to be considered?***
   Sub-Questions:
   How was the design of the PSS for your company?
   What did the process of designing the PSS look like?
   Did you use a specific framework from theory/ consulting company for the design/ development of your PSS?
7) ***What is Sustainability for you/ your company?***
   Sub-Question:
   Starting point: the interviewee probably mentions relating to the questions before sustainability. *You were talking about sustainability… We would like to go deeper on this topic… What is Sustainability for you/your company? Why are you considering sustainability?*
8) ***Do you think there is a difference between a PSS and a sustainable PSS?***
   Sub-Questions:
   If yes: What is the difference between a PSS and a sustainable PSS?
   If no: Why are they the same?
   → Possible popping up problem: the interviewee can ask the question:" what do you mean for sustainable PSS?". Then the answer will be regarding the fact that PSS is not sustainable by definition and that sustainability must be strategically integrated.
9) **If you would design a fully sustainable PSS, what would you integrate?**
   Sub-Questions:
   Starting point: compare their current PSS offering which integrates sustainability vs standard PSS offering without sustainability. "*What's the difference between your PSS offering integrating sustainability and a standard PSS offering?*" Then there will be a comparison between their PSS offering integrating sustainability and an ideal sustainable PSS: *"do you think that your PSS can be recognized as a sustainable PSS?" "Why?"*
10) ***How have you integrated Sustainability in the Design of the PSS?***
    How have you integrated
    Environmental Sustainability?
    Societal/ Social Sustainability?
    Economical Sustainability?
    your **Stakeholders** (their needs and in the design process itself)?
    *(Which Stakeholders of your company were **integrated** during the **design process**? (experts/universities/customers/suppliers) Which stakeholders and their **needs** are considered in the design of the PSS? How were they considered?)*
    Which part of the **Life-Cycle** have you covered in the design of your PSS?
    If the interviewee considers his PSS as sustainable: *"How have you designed it? How have you integrated sustainability and its core aspects in the design stage?"*
    If the interviewee considers his PSS **NOT (enough)** sustainable: *"How have you designed it? How have you integrated sustainability and its core aspects in the design stage? Is there any missing aspects regarding sustainability you would include? How would you integrate them? Why have you not integrated those aspects in the design?"*
11) ***If you would make a briefly conclusion regarding the questions that we asked, what are the most critical factors as practitioner when designing a sustainable PSS?***
    Sub-Question:
    What challenges did you face when integrating sustainability in the design of the PSS? Have some aspects about sustainability disappointed your expectations when tangibly applied to PSS?

Appendix F: Rationale behind the Interview Questions

Question #	Relationship with our RQ
from #1 to #6	These questions don't contribute in answering our RQ. However, they help us in understanding the context of the interviewee and they work as an introduction for the furthermore important questions of the interview.
#7	Question to understand which is the model of sustainability adopted by the interviewee.
#8	Investigation on the criteria adopted by the interviewee in integrating sustainability in his PSS.
#9	Question addressing our preliminary definition of sustainable PSS. We recognize the importance for a PSS to have a system perspective. We think that a PSS has a system perspective when those aspect were integrated. We ask if they think that those aspects are important when design a PSS and how they would approach in integrating them. Can those aspects be effectively integrated or are they out of the company's control?
#10 and #11	Interviewee definition of sustainable PSS. His definition and his thoughts can then be compared with the academic findings for the development of our definition.
#12	Question regarding the blind spots that the interviewee has recognized implementing sustainability. Helpful question that can allow us to have a more precise business perspective that the literature may not provide.