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Review

Product services for a resource-efficient and circular economy – a review

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ABSTRACT

Since the 1990s, Product Service Systems (PSS) have been heralded as one of the most effective instruments for moving society towards a resource-efficient, circular economy and creating a much-needed 'resource revolution'. This paper reviews the literature on PSS in the last decade and compares the findings with those from an earlier review in this journal in 2006. Close to 300 relevant papers were identified, over 140 of which have been referenced in this review. Research in the field of PSS has become more prolific, with the output of refereed papers quadrupling since 2000, while on average scientific output has only doubled. PSS has also become embedded in a wider range of science fields (such as manufacturing, ICT, business management, and design) and geographical regions (Asia now produces more papers than Europe). The literature of the last seven years has refined insights with regard to the design of PSS, as well as their business and environmental benefits, and confirmed the definitions and PSS concepts already available in 2006. A major contribution of the recent literature is research into how firms have implemented PSS in their organization and what the key success factors and issues that require special attention are (such as a focus on product availability for clients; an emphasis on diversity in terms of services provided rather than the range of products; and the need for staff to possess both knowledge of the product and relationship management skills). The reasons why PSS have nonetheless still not been widely implemented, particularly in the B2C context, seem to have already been explained fairly well in the literature available in 2006. For consumers, having control over things, artifacts, and life itself is one of the most valued attributes. PSS are often less accessible, or have less intangible value, than the competing product, in part because PSS usually do not allow consumers as much behavioral freedom or even leave them with the impression that the PSS provider could prescribe how they should behave.

1. Introduction

Product-service systems (PSS) are a specific type of value proposition that a business (network) offers to (or co-produces with) its clients. One definition of PSS is '*a mix of tangible products and intangible services designed and combined so that they are jointly capable of fulfilling final customer needs*' (Tukker and Tischner, 2006a). From the mid-1990s, PSS became a popular subject for researchers engaged with sustainability and business alike. Sustainability researchers argued that if one were to focus on final user needs or the service a user wants, rather than the product, it would become much easier to design need-fulfillment systems with radically lower impacts. In product-oriented business models firms have the incentive to maximize the number of products sold. This is their principal method of boosting turnover, increasing market share, and generating profits. However in service-oriented business models, in theory the incentive differs. Firms then make money by being paid for the service offered, and the material products and consumables that play a role in providing the service become cost factors. Hence, firms will have an incentive to prolong the service life of products, to ensure they are used as intensively as possible, to make them as cost- and material-efficiently as possible, and to re-use parts as far as possible after the end of the product's life. All of these elements could lead to a minimization of material flows in the economy while maximizing service output or user satisfaction.

Authors such as Walther Stahel (1982) and Friedrich Schmidt-Bleek (1993) were pioneers in identifying these benefits of the PSS concept in terms of sustainability and resource-efficiency. This

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interest in PSS for environmental reasons has received a new boost from the recent revival of interest in resource-efficiency among important actors in civil society, business and government. With up to three billion people likely to join the global middle class by 2050 (WBCSD, 2009; McKinsey, 2011), competition for resources will inevitably grow. Improving the productivity of resources such as water and land by around a factor of two, and energy by a far higher factor, would make a substantial contribution to reducing resource depletion and the threat of climate change (McKinsey, 2011; BIO IS, 2012; Tukker, 2013). The European Union (EU) has therefore designated resource-efficiency as one of the flagships of its Europe 2020 strategy (EC, 2011). For the reasons given above, influential authors from civil society and policy makers see PSS-like business models as one of the most important means of creating a 'lease society' (a term coined by Member of the European Parliament Judith Merkies (2012)), a circular economy (as championed by the Ellen McArthur Foundation (2013)) or simply a 'resource revolution' (McKinsey, 2011).

For the business community, the growing interest in new PSS business models initially arose from the growing realization that in most markets products became all of similar and high quality making the room for product differentiation limited. Design and manufacture of products could no longer be a source of differentiation and competitive advantage. To overcome sheer price competition, firms had to offer integrated solutions, or even experiences, which would allow them to improve their position in the value chain, increase their innovation potential, and enhance the added value of their offering (Pine and Gilmore, 1999).

Given the promise held out by PSS, around 2000 a wave of major research projects started, mainly in Europe, where a few dozen major research institutes tried to develop a structure for classifying PSS. Their aim was to create a rigid scientific foundation for the concept and to learn from case studies when it would and would not work (e.g. Tukker, 2004). One of these projects was 'SusProNet', a network that served as one of the hubs in which PSS scientists could exchange experiences and views. At the end of that project, Tukker and Tischner (2006a,b) wrote a review that was quite critical of sustainability-oriented PSS research:

- Case research was often driven by normative sustainability goals and failed to analyze the reasons for poor PSS implementation, such as a lack of consumer acceptance or business interest.
- There was too much concentration on individual case studies and conceptual development, and no rigorous quantitative or statistical analysis of large numbers of cases.
- The sustainability-oriented PSS research community paid only limited attention to business management literature.

The result of these shortcomings was that PSS was at that time a pre-paradigmatic field that still lacked clearly tested hypotheses and insights. Since then, attention to the PSS concept has deepened, particularly in the business research community. Organizations like Cranfield Business School received major grants and started to work with large companies such as Rolls Royce to analyze their service-oriented business models and to understand what would work and not. Since 2000, this has led to considerable advances in the field.

It therefore seems appropriate to follow up the reviews performed in 2004 and 2006 with a new paper that takes stock of developments since then and answers questions such as:

1. Is there a clear, uniform definition of the PSS concept?
2. Is there a clear, common approach to PSS development?
3. What do case studies and other scientific approaches tell us about
   - the conditions under which PSS contributes to sustainability?
   - the conditions under which PSS enhances competitiveness?

   Are these insights more specific or do they reveal more than hypotheses formulated some eight to ten years ago (e.g. Mont, 2002; 2004a; Halme et al., 2004; Tukker and Tischner (2006a,b)? Can these insights help to determine whether PSS contribute to resource-efficiency and to answer the main question addressed in this special issue: *'Why have sustainable Product-Service Systems not been widely implemented?'*
4. Is PSS now a consolidated science field with a clear paradigmatic concept and tried and tested research hypotheses?

In this paper I review the vast majority of the literature dedicated to PSS from a business and sustainability perspective available today. I selected 278 relevant papers and use them to provide some quantitative insights into how research in the PSS field has developed in the last 15 years (Section 2). This section also includes a discussion of how the selection of papers and the research approach differ from another recent review published in this journal (Boehm and Thomas, 2013).[1] We then use a selection of these references to answer the key questions posed above (Section 3) and end with a discussion of the findings and some conclusions (Section 4). Where relevant, we do so with other major reviews in the PSS field in mind (Boehm and Thomas, 2013; Berkovich et al., 2011[2]; Pawar et al., 2009; Cavalieri and Pezzotta, 2012; Baines et al., 2007; 2009a; Sakao et al., 2009; Park and Lee, 2009; Meier et al., 2010).

2. The product-service literature since the late 1990s

2.1. Selection of references

The evaluation is confined to publications in the formal literature and does not include books, 'grey' research reports, etc. I used Scopus as the basis for the literature search. Scopus is a bibliographic database containing abstracts and citations for academic journal articles. Falagas et al. (2008) suggest that compared to alternatives like the Web of Science and Google Scholar, Scopus, due to a wider subject and journal range, is probably currently the best tool available for electronic literature search, particularly for articles published after 1995.

Scopus contains an estimated 40 million articles.[3] The initial search using the key words 'product' and 'service' and 'system' generated 27,000 documents.[4] Adding 'sustainability' as a key word reduced the number of documents to 1773. Most of these documents had little to do with PSS and merely happened to contain all the key words in the abstract or title. The top 600 articles in this list, by number of citations, were checked manually to determine, on the basis of the title (and if necessary the abstract), whether the

[1] Boehm and Thomas focus mainly on the definition of PSS and do not discuss the other two main questions addressed in this review.

[2] Boehm and Thomas also mention Berkovich, M., Esch, S., Leimeister, J.M., Krcmar, H., 2009. Requirements engineering for hybrid products as bundles of hardware, software and service elements – a literature review, in: Wirtschaftsinformatik Proceedings 2009, Paper 67. Since the title is the same as Berkovich et al., 2011, it is likely to cover the same subject matter.

[3] This estimate was made by entering the simple key word 'The' in the Scopus search engine, which is likely to be used in all papers in the English-language domain. This resulted in some 40 million search results, which could be further classified by year of publication. This resulted in the estimate made later in this paper that the number of publications listed annually in Scopus rose from one million in 2000 to two million in 2010.

[4] The literature extraction was finalized around 20 December 2012. All of the figures quoted in this paper, such as citation data, therefore relate to the status quo on that date.

subject matter was PSS as meant in this special issue. The analysis of the top 600 yielded 67 papers, with two citations for the least cited paper and 202 for the most cited paper (Mont, 2002). It was assumed that papers with fewer citations would not have had sufficient impact or relevance to be considered.[5]

Another assumption was that the authors who had written the most frequently cited papers would form a nucleus in PSS research. Hence, I checked the publication record of the authors of the top 30 papers by citation (with 13 citations or more) in Scopus and added relevant publications to the original list of 67. This produced a list of 113 papers in all. I then anticipated that papers that cited this core set would probably also deal with PSS. The 113 papers were cited 2076 times in total, in 1095 papers. The titles, and if necessary the abstracts, of these 1095 papers were again checked manually to determine whether they dealt with PSS. This ultimately resulted in the final list of 278 papers that form the basis of the review in this paper.

Creating such a base list of references is inevitably the result of choices which are, to some extent, arbitrary. I wrote this paper on invitation for this special issue, but as it happened, during the time of writing another major review of PSS was published in this journal (Boehm and Thomas, 2013). It is interesting to note that both review papers used a well-structured and rigorous selection process leading to almost the same number of relevant references (278 in this paper and 265 in the paper of Boehm and Thomas, 2013). Yet, while the lists overlap for some 50%, they clearly have different characteristics, as listed below.

- By focusing on Scopus, 'grey' literature, such as contract research reports, has been consciously omitted. I believe this is acceptable: a special issue of a scientific journal like this should refer mainly to peer-reviewed literature, and 'grey' literature that has scientific value usually ends up in condensed form as a paper in the scientific literature (e.g. Manzini and Vezzoli, 2003; Tukker and Tischner, 2006b; Evans et al., 2007). Boehm and Thomas (2013), however, did include such 'unofficial' literature (e.g. Ceschin, 2010), including references to unofficial proceedings edited by myself and others (e.g. McAloone, 2006).
- I focused entirely on the English-language domain. Boehm and Thomas (2013), with Boehm being from the German-language domain, included a few dozen references to papers in German (e.g. Meier et al., 2005). However, since this paper covers international references from the most important German research groups (e.g. Meier et al., 2010; Aurich et al., 2006a,b), I feel that very much the same literature is covered here.
- I also focused on authors that clearly defined themselves as publishing on the subject of PSS (or related concepts, such as Industrial Product Service Systems or IPS2). In the business literature, there are authors (probably much larger in number) who focus on business models in general, delivery of integrated solutions, and experience design (e.g. Wise and Baumgartner, 1999; Davies et al., 2003; Lasalle and Britton, 2003). While this literature provides interesting insights into the business value and design of PSS, I did not want to cover it comprehensively in this review; first, it would explode the number of references to be covered, but more importantly, the focus of this special issue is on authors who brand themselves as being engaged in the field of 'PSS' and not as general business modelers. Boehm and Thomas (2013) were also interested in authors who did not necessarily brand themselves as PSS researchers, but who worked in fields like Information Systems and Business Management and published on PSS-like business models in that context, although using different names for it.

Since both reviews are ultimately based on roughly the same number of papers, it is therefore likely that our review covers more papers from the PSS/IPS2 field in the strict sense. By using the key words Product Service Systems, manually adding all relevant publications of top cited authors in the PSS field, and including all relevant publications of those who cited them, I feel there is little chance that any highly cited or high impact papers have been missed. Indeed, if there is any bias it is probably that various papers from adjacent fields were included during the two manual checks. Even if the key words and abstract did not include the term PSS or IPS2, papers were retained if they were frequently cited and discussed a subject clearly overlapping with PSS (for example, service strategies for manufacturing).

2.2. Analysis of references

It is interesting in and of itself to analyze some basic characteristics of the selected articles, such as year of publication, science field covered, the journal in which they appeared, etc. This analysis is provided below.

Fig. 1 shows the number of papers published in each year. Over half of all the papers were published in 2010, 2011 and 2012. A noteworthy aspect is the relatively large number of papers on PSS published in 2004 and 2006. This is partly a reflection of the impact of some major EU projects that ended in that period and led to publications and partly a consequence of special issues of the Journal of Cleaner Production (Mont and Tukker, 2006; Mont, 2003). Fig. 2 shows that environment is not (if it ever was) the main subject of papers on PSS. Scopus can label papers in more than one subject area, which explains why the number of papers classified by subject area is higher than the actual number of papers. More papers relate to engineering, computer science and business, management and accounting, suggesting that PSS research from a business perspective has become more important than environmental research.

Tables 1–4 give the numbers of papers by author, affiliation, country and journal. The Journal of Cleaner Production is the dominant source title (due in part to the publication of three special issues on PSS), followed by two journals in the field of manufacturing. Cranfield University, with its Innovative Manufacturing Research Centre which adopted PSS as one if its main theoretical concepts, has clearly been the dominant contributor to PSS research in recent years. Cranfield is followed by

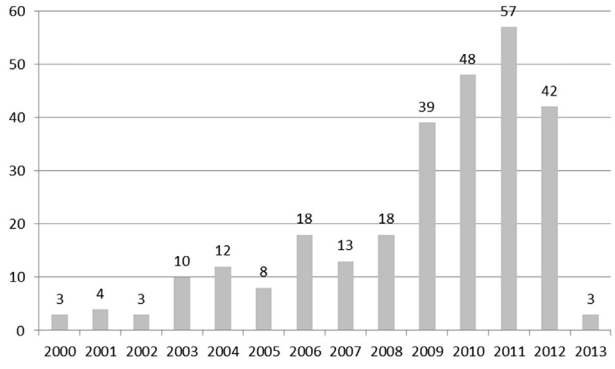

Fig. 1. Number of papers per year of publication (status on 18 December 2012).

[5] The 67 selected papers were published between 1998 and 2012. Two factors probably explain why there are no papers from the period before 1998: Scopus contains comprehensive coverage of literature from 1996 (although it also covers a significant number of papers from before that date), and the concept of PSS was developed in the late 1990s.

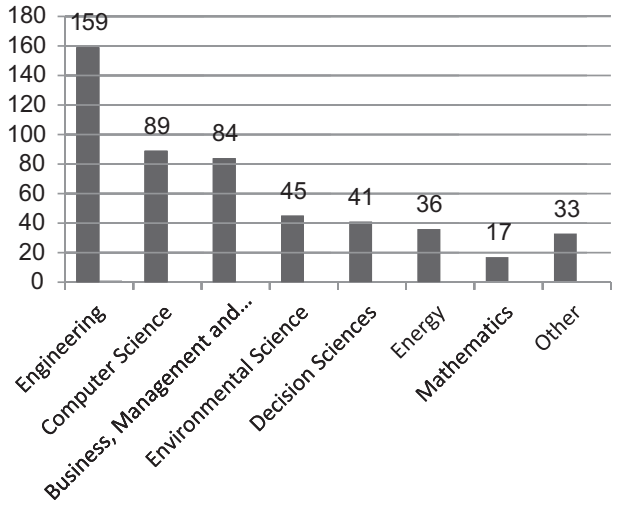

Fig. 2. Number of papers per Scopus subject area (status on 18 December 2012; the same paper may cover more than one subject area).

institutes in Asia, like Seoul National University and Shanghai Jaiotong University. Sweden is strongly represented via Linköping University and Lund University. Not surprisingly, this leads to a country list led by the UK, with China, Germany, Sweden, the US and South Korea being other countries very active in publishing on PSS. The list of authors with most publications contains some well-known names in the field, including Oksana Mont (Lund University), Raykumar Roy (Cranfield University), Jan Aurich (University of Kaiserslautern) and Yongtae Park (Seoul National University).

Table 5 lists papers by number of citations. It is interesting to note that some authors who are not among those to have published the most papers have written papers that are among the most cited. Examples are Manzini and Vezzoli (2003), Tukker (2004), Maxwell and Van der Vorst (2003), Baines (see Baines et al., 2007) and Tischner (see Tukker and Tischner, 2006a). What is also apparent is that the list of highly cited papers – apart from those that were published some time ago and could therefore accumulate citations over time – consists predominantly of conceptual papers (e.g. Roy, 2000; Mont, 2002; Tukker, 2004), state of the art reviews (e.g. Baines et al., 2007; Tukker and Tischner, 2006a), and papers on PSS design methods (Aurich et al., 2006a; Morelli, 2006; Manzini and Vezzoli, 2003; Maxwell and Van der Vorst, 2003). This is not entirely surprising, since they have a much more generic scope and hence are far more relevant for other authors than individual case study analyses, for example. It is quite striking that all of the most frequently cited papers seem to be by European authors. This probably has to do with the fact that PSS was conceptualized in Europe in the 1990s and that European authors were therefore among the first to write conceptual and methodological papers that do well in citation lists. The output of the Asian universities in Table 3 was generated mainly in the latter half of the last decade. The absence of North American authors from the list of highly cited papers is also striking. This contrasts with the findings of Baines et al. (2007, 2009a) and is probably related to the fact that they looked at servitization literature in a broad sense, while this paper focuses on terms like product-services, PSS, and IPS2, which seem to have a European origin.[6]

The most interesting conclusions from this concise analysis are probably the following. First, the clearly rising number of papers shows that the interest in the PSS concept was not a temporary phenomenon fueled by a string of EU projects launched around 2000. Scientific output of PSS-related papers increased four- to five-fold in the decade between 2000 and 2010. This is a substantial increase, even correcting for the general trend that more papers are being published – the number of articles listed annually in Scopus doubled from roughly one million in 2000 to two million in 2010. Second, we see that the concept is probably even more firmly embedded in the engineering and business literature than in the

Table 1
Top 15 authors ranked by number of PSS publications (status on 18 December 2012).

	Author name	
1	Park, Y.	10
2	Sakao, T.	9
3	Roy, R.	9
4	Aurich, J.C.	8
5	Mont, O.	8
6	Geum, Y.	7
7	Jiang, P.	6
8	Sundin, E.	6
9	Shimomura, Y.	6
10	Schweitzer, E.	5
11	Lindahl, M.	5
12	Meier, H.	5
13	Evans, S.	5
14	Tiwari, A.	5
15	Lee, S.W.	4

Table 2
Top 15 institutions ranked by number of PSS publications (status on 18 December 2012).

	Affiliation	
1	Cranfield University	29
2	Seoul National University	14
3	Shanghai Jiaotong University	13
4	Linköpings universitet	11
5	Lunds Universitet	10
6	Tokyo Metropolitan University	8
7	Universität Bochum	8
8	Sungkyunkwan University	8
9	Technische Universität Darmstadt	8
10	Danmarks Tekniske Universitet	8
11	Luleå tekniska Universitet	7
12	Technische Universität Kaiserslautern	7
13	State Key Laboratory for Manufacturing Systems Engineering	7
14	Delft University of Technology	6
15	University of Bath	6

Table 3
PSS publications by country of origin of the publishing institution (status on 18 December 2012).

	Country	
1	United Kingdom	60
2	China	41
3	Germany	37
4	Sweden	31
5	United States	25
6	South Korea	23
7	Italy	16
8	Netherlands	13
9	Japan	12
10	Denmark	11
11	France	8
12	Finland	7
13	Australia	6
14	Canada	6
15	Austria	4

[6] Baines et al. (2009a) discern five strands of literature that describe the servitization of manufacturing in one way or another: servitization, PSS, service marketing, service operations and services science. With its primary focus on PSS, this paper does not aim to cover this broader field.

Table 4
PSS publications by journal (status on 18 December 2012).

	Source title	
1	Journal of Cleaner Production	25
2	Journal of Manufacturing Technology Management	14
3	International Journal of Advanced Manufacturing Technology	11
4	International Journal of Operations and Production Management	8
5	Iced 11 18th International Conference on Engineering Design	8
6	Computers in Industry	7
7	CIRP Annals Manufacturing Technology	7
8	CIRP Journal of Manufacturing Science and Technology	6
9	Journal of Service Management	6
10	Proceedings of the ASME Design Engineering Technical Conference	6
11	International Journal of Internet Manufacturing and Services	5
12	International Journal of Computer Integrated Manufacturing	5
13	IFIP Advances in Information and Communication Technology	5
14	Proceedings of the 14th CIRP Conference on Life Cycle Engineering	4
15	International Journal of Production Research	4

environmental literature. Third, we see that whereas the PSS concept was born in Europe, it later clearly found a resonance particularly in Asian countries – all but four of the 41 Chinese papers and all but one of the 25 Korean papers date from 2009 or later. The detailed conclusions concerning authors with high numbers of publications in this paper, for example, differ slightly from those of Boehm and Thomas (2013) due to the different base set of papers used, as discussed earlier. The more overarching conclusions, however, do not differ fundamentally from what Boehm and Thomas (2013) found in their review.

3. Progress in insights about PSS

3.1. Introduction

After this concise quantitative analysis of papers, we turn to contents. Reviewing a selection of the 278 papers that were inventoried, I want to analyze whether progressive insight has been acquired since around 2005 on the following subjects:

1. (further) specification of the PSS concept
2. (further) specification of the approach to PSS development
3. (novel) insights about the conditions under which
   - PSS contributes to sustainability
   - PSS enhances competitiveness
4. whether PSS is now a consolidated science field with a clear paradigmatic concept and tried and tested research hypotheses.

This also implies that the focus of this review of the state of the art is different to that of the recent review by Boehm and Thomas (2013) in this journal. Boehm and Thomas (2013) were mainly concerned with the first point above, set out to derive a PSS definition and classification from the literature across the fields of Information Systems, Business Management and Engineering and Design, and then directly moved to establishing a research agenda. In contrast to Boehm and Thomas (2013), I focused mainly on literature from the Engineering and Design field and address the four issues mentioned above in the following sections. The review of subject 3, in particular, could help to ascertain whether PSS can contribute significantly to resource-efficiency and circularity. First, it helps to establish whether PSS are sustainable per se, and second, it indicates whether firms are generally likely to take up PSS as new business models. That will in turn help to answer the main question of this special issue: why have sustainable PSS not been widely implemented?

Table 5
Top 20 papers by number of citations (status on 18 December 2012).

Year	Authors	Document title	Citations
2002	Mont O.K.	Clarifying the concept of product-service system	202
2007	Baines T.S., Lightfoot H.W., Evans S., et al.	State-of-the-art in product-service systems	187
2002	Menor L.J., Tatikonda M.V., Sampson S.E.	New service development: Areas for exploitation and exploration	165
2001	De Brentani U.	Innovative versus incremental new business services: Different keys for achieving success	141
2001	Dangayach G.S., Deshmukh S.G.	Manufacturing strategy Literature review and some issues	125
2001	Mathieu V.	Service strategies within the manufacturing sector: Benefits, costs and partnership	103
2004	Tukker A.	Eight types of product-service system: Eight ways to sustainability? Experiences from SusProNet	99
2006	Aurich J.C., Fuchs C., Wagenknecht C.	Life cycle oriented design of technical Product-Service Systems	89
2008	Srivastava S.K.	Network design for reverse logistics	83
2004	Alonso-Rasgado T., Thompson G., Elfstrom B.-O.	The design of functional (total care) products	83
2003	Maxwell D., Van der Vorst R.	Developing sustainable products and services	82
2003	Manzini E., Vezzoli C.	A strategic design approach to develop sustainable product service systems: Examples taken from the 'environmentally friendly innovation' Italian prize	81
2003	Brown S., Bessant J.	The manufacturing strategy-capabilities links in mass customization and agile manufacturing – An exploratory study	75
2008	Basole R.C., Rouse W.B.	Complexity of service value networks: Conceptualization and empirical investigation	73
2005	Stevenson M., Hendry L.C., Kingsman B.G.	A review of production planning and control: The applicability of key concepts to the make-to-order industry	70
2006	Tukker A., Tischner U.	Product-services as a research field: past, present and future. Reflections from a decade of research	62
2000	Spring M., Dalrymple J.F.	Product customization and manufacturing strategy	62
2006	Morelli N.	Developing new product service systems (PSS): methodologies and operational tools	58
2002	Van Der Aa W., Elfring T.	Realizing innovation in services	58
2000	Roy R.	Sustainable product-service systems	57

3.2. The PSS concept

3.2.1. Literature from 2006 and earlier

Table 6 lists definitions from the formative years of the PSS concept. As also noted by Baines et al. (2007), all of these definitions essentially refer to "product(s) and service(s) combined in a system to deliver required user functionality". Some authors require that a PSS must by definition be more sustainable than the competing product concept (e.g. Mont, 2004a). Others define it merely as a combination of product and service and add the adjective 'sustainable' when the PSS is indeed more sustainable than the competing product concept (Tukker and Tischner, 2006b).

Various classifications of product-services have been proposed (e.g. Behrend et al., 2003; Brezet et al., 2001; Zaring et al., 2001). The different types of product-services differ in the extent to which

their value is determined by the product or the service component. Only Hockerts and Weaver (2002) deviate slightly from this approach, by using the extent to which the property rights of the offering vest in the user or provider as a measure of defining a PSS. Most classifications make a distinction between three main categories of PSS (Tukker, 2004)[7]:

- The first category is product-oriented services. Here, the business model is still mainly geared towards selling products, but some additional services are added. Sub-categories are product-related services (e.g. insurance or maintenance contracts) and advice and consultancy.
- The second category is use-oriented services. Here, the traditional product still plays a central role, but the business model is not geared towards selling products. Ownership of the product remains with the provider, it is made available in a different form, and it is sometimes shared by a number of users. Sub-categories are product leasing (use by a single user), product renting or sharing (sequential use by different users), or product pooling (simultaneous use of the product by various users, e.g. car pooling).
- The final category is result-oriented services. Here, the client and provider agree in principle on a result and there is no pre-determined product involved. Sub-categories are activity management/outsourcing (e.g. catering services), pay-per-service unit (e.g. payment per copy made in copying; per km driven in fleet management; or per airplane landing in tire management services), or functional result. As already mentioned, this type of PSS is the most promising in terms of facilitating a shift to a circular and resource-efficient economy, since the profit center is now the result delivered rather than the product sold. All material products and consumables used to deliver the result now become cost factors, creating an incentive to minimize their use.

3.2.2. Literature from 2006 and later

In more recent literature, authors sometimes still come up with their own definitions of PSS, although in most cases they do not differ fundamentally from the concepts defined in the period just after 2000. Examples are:

- An Integrated Product Service System (iPSS) "is a systematic package in which intangible services are attached to tangible products to finish various industrial activities in the whole product life cycle" (Zhang et al., 2012: 1579);
- "Elements of PSS [are]: product, service, and supporting networks and infrastructure; Goals of PSS [are]: strives to be competitive; maximum customer value; lower environmental impact (Wang et al., 2011a,b)";
- "integrated service products (ISP) – in the product sales stage, to meet the clients' multi-level needs, the manufacturer provides customers with "physical product plus service" service packs; whereas, physical product is the carrier of product service, and product services are function added and the value added for the physical product. However, since the ISP combines characteristics of both physical products and services, it becomes the most complex product type" (Li et al., 2012);
- By supplying an integrated bundle of hardware, software, and service elements, the customer problem is solved completely. These bundles are known as product service systems (PSS) or hybrid products (Berkovich et al., 2011).

Table 6
PSS definitions coined in the formative years of the field.

PSS definitions and connected terms	Source
A Product-Service System is defined as "a marketable set of products and services capable of jointly fulfilling a user's needs"	Goedkoop et al. (1999), p. 18
PSS is a system of products, services, supporting networks and infrastructure that is designed to be competitive, satisfy customers' needs and have a lower environmental impact than traditional business models.	Mont (2004a)
Eco-efficient services are systems of products and services which are developed to cause a minimum environmental impact with a maximum added value.	Brezet et al. (2001)
An eco-efficient service is one which reduces the environmental impact of customer activities per unit of output. This can be done directly (by replacing an alternative product-service mix) or indirectly (by influencing customer activities to become more eco-efficient).	James et al. (2001)
A *Product-Service System* can be defined 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); also used in the EU FP5 project MEPSS (van Halen et al., 2005)
A pure product system is one in which all property rights are transferred from the product provider to the client on the point of sale [..]. A pure service system is one in which all property rights remain with the service provider, and the clients obtain no other right besides consuming the service. A product-service system is a mixture [..] of the above. It requires that property rights remain distributed between client and provider, requiring more or less interaction over the life time of the PSS	Hockerts and Weaver (2002)
A Product-Service System consists of tangible products and intangible services designed and combined so that they are jointly capable of fulfilling specific needs of customers	Tukker and Tischner (2006b; definition used in SusProNet)

There are some exceptions. For example, in a broad review of business modeling literature, including PSS, Lay et al. (2009) define eight parameters that differentiate the models: ownership during use and at end of life; financing; maintenance personnel; payment; number of customers; location of the operation; and retrieval and recycling. They then describe the options for providing each feature (for example, for ownership: the equipment producer, a leasing bank, an operating joint venture or the customer). This results in a morphological box that allows for a fine-grained characterization of product-service-like business models (see Fig. 3). Park et al. (2012) arrive, on the basis of a broad

[7] Obviously, there are authors who use slightly different classifications. Komoto et al. (2005) do not mention the 'product-oriented service', but, in addition to the 'Functional sales' and 'sharing' models, distinguish a 'Commercial' model, which can probably best be described as 'pure service', and the 'Traditional model', in which they combine the 'pure product' and 'product-oriented service' models. Michelini and Razzoli (2004a) discern the provision of 'tangibles' (products and product-oriented services, or leased products) or 'intangibles' (sharing and pooling; function-oriented services), in essence following Hockerts and Weaver's (2002) division according to who owns the property rights to the product.

review, at a differentiation between market-oriented IPS and engineering-oriented IPS. They further develop what they call an 'IPS Cube', whose dimensions are the role of technology (technology-free or otherwise), the ownership of the product (customer or provider), and the nature of the integration (mixed or compound). Cedegren et al. (2012) identify the following five themes that need to be included to describe PSS: delivery, processes, value creation networks, knowledge management, and business models. In essence, one could say that these and other authors (e.g. Kim et al., 2011a,b, c, 2010a,b; Lee and Abuali, 2011) have formulated refinements of the definition or characterization of PSS, by refining characteristic features, options for provision, or other dimensions of PSS.

In their review, Boehm and Thomas (2013) adopted an interesting approach by making use of 'definition graphs' to analyze how words were linked together as defining elements for the PSS concept in the Information Systems, Business Management and Engineering and Design disciplines. This led them to propose that the following definition would be acceptable in every field: *'A Product-Service System (PSS) is an integrated bundle of products and services which aims at creating customer utility and generating value.'* While on the surface not entirely different to earlier definitions, it rightly emphasizes that the combination of products and services needs to create utility for customers and value for providers. They do not offer a further sub-classification of PSS.

Unlike the pre-2006 literature, the post-2006 literature contains little discussion about the relationship between the features that characterize a PSS concept and its sustainability potential. This may be connected with the fact that most of the literature from after 2006 focuses on new business development and improving competitiveness rather than on sustainability. Furthermore, despite the apparent conceptual agreement about how to define and classify PSS, authors such as Vasantha et al. (2012) noted that at a more specific level a common terminology and ontology is still a long way off, which hinders a common framing and understanding of outstanding research questions.

3.3. PSS design methodologies

3.3.1. Literature from 2006 and earlier

In the period after 2000, a variety of guidelines for PSS development were produced. One of the most widely disseminated is UNEP's Design for Sustainability manual, which includes a PSS module (Crul et al., 2009).[8] Other manuals from that time were the result of the Sustainable Product Development Network (SusProNet) project (See Annex 1 in Tukker and Tischner, 2006b), the Method Product Service Systems (MEPSS) project (van Halen et al., 2005), and many other initiatives (e.g. James et al., 2001; Morelli, 2006; Tukker and van Halen, 2003; Brezet et al., 2001; Manzini et al., 2004; Halme et al., 2004; Maxwell and Van der Vorst, 2003). The SusProNet project made a cross-analysis of most of the methods available around 2006, which showed that although the steps in the methods differed somewhat, they could be clearly grouped into three main blocks (Tukker and Tischner, 2006b):

1. Analysis: assessment of strengths and weaknesses of the current product portfolio and markets, decision making in priority areas where PSS development could be beneficial for client and firm;
2. Idea generation, selection, refinement and evaluation (finding ideas, selecting the most promising ones, and detailed design)[9];
3. (Planning and preparing) implementation.

The methods described above are usually supported by dedicated tools and worksheets on aspects such as idea generation and creativity enhancement; economic, social and environmental evaluation; visualization of the PSS in the form of a storyboard; and description of the PSS business model in terms of technical architecture, organizational architecture, and revenue streams, including the need for setting up new partnerships to deliver the PSS ('make or buy' decisions)[10,11]. Fig. 4 gives a summary of the PSS development method suggested by the UNEP manual (Crul et al., 2009). Despite appearances, most of the aforementioned methods show a healthy sensitivity to the fact that PSS design is not usually a linear process, but is an iterative affair and does not necessarily start with a top–down strategic SWOT analysis of the product and market portfolio; it can also start with straightforward ideas generated in producer–client interactions. Methods developed by sustainability researchers, in particular, include guidelines that help to focus on longevity, re-use and recycling, in the analysis, idea generation and implementation phases of PSS design (e.g. Tukker and Tischner, 2006a; Crul et al., 2009).

3.3.2. Literature from 2006 and later

The literature published in 2006 and later reveals no shortage of PSS design methods. Recent reviews include Aurich et al. (2010), McAloone (2011), Sakao and McAloone (2011) and Vasantha et al. (2012). Some papers focus on specific methods and tools to be used within a design procedure – a number of them are summarized in Table 7. Papers describing an integrated PSS development trajectory include the following.

- Like most of the aforementioned authors, Aurich et al. (2006a) propose a step-by-step process. They essentially translate the traditional process of product design involving idea finding, concept development, product construction, product detailing, prototype development, and manufacturing preparation into a process of technical service design involving demand identification, feasibility analysis, concept development, service modeling, realization/planning and service testing, and propose a parallel, interactive process of product and service development for PSS.
- Aurich et al. (2006b) and others (e.g. Wang et al., 2011a; Li et al., 2012) further emphasize the relevance of a modular design of product and service development. The modules would consist of the phases in product and service design already mentioned above, as well as a set of standardized tasks to be executed in each phase. This modularity would have the advantage of enhancing the speed of new PSS development, allowing for new

[8] While only published in 2009, this manual was in preparation for a long time and in fact represents the design approach for PSS developed in the period up to 2006 – most authors of that manual were in fact involved in or drew upon the string of EU projects relating to PSS that were concluded around 2005.

[9] Various authors suggest using the TRIZ methodology as a basis for PSS idea generation (e.g. Low et al., 2000; Chai et al., 2005; for later work see Rovida et al., 2009; Kim and Yoon, 2012). TRIZ is the theory of inventive problem solving developed by Altshuller and colleagues after the Second World War. The hypothesis behind TRIZ, which is substantiated by meta-analyses of innovative processes, is that there are around 40 key universal principles that lie behind all creative innovation. It is postulated that by using these principles in brainstorming and creativity processes for solving a specific problem, a comprehensive set of new solutions can be found (Kim and Yoon, 2012).

[10] These approaches have a lot in common with New Service Design methodologies, as described for instance by Menor et al. (2002). They also describe a gate-stage process of design (strategy formulation, idea generation and screening and concept development), analysis (detailed analysis of the business case and authorization), development and full launch.

[11] Compare Kim and Mauborgne's Strategy Canvas (Kim and Mauborgne, 2002).

Characteristic Features		Options			
Ownership	during phase of use	Equipment producer	Leasing bank	Operating joint venture	Customer
	after phase of use	Equipment producer	Leasing bank	Operating joint venture	Customer
Personnel	Manufacturing	Equipment producer	Operating joint venture	Customer	
	Maintenance	Equipment producer	Operating joint venture	Customer	
Location of operation		Equipment producer's establishment	Establishment "fence to fence" to the customer	Customer's establishment	
Single / multiple customer operation		In parallel operation for multiple customers	Operation for a single customer		
Payment model		pay per unit	pay for availability	fixed rate	pay for equipment

Fig. 3. Morphological box as developed by Lay et al. (2009) as a framework to describe new product-service oriented business concepts.

Steps in the pilot project	Suggested tools
1. Exploring opportunities: identification and analysis of the existing reference system	- *Drawing a system map/ Blueprinting* - *Sustainability SWOT* - *Checklist for analysing existing reference system*
2. PSS idea generation and selection of the most promising concepts	- *Sustainability Guidelines Level 1* - *Format of PSS concept description* - *PSS Sustainability Screening Tool* - *Portfolio Diagram Sustainability and Feasibility*
3. Detailing selected PSS concepts or PSS design	- *Sustainability Guidelines level 2* - *Extended system map of the new system/ blueprint* - *Extended description of the new system* - *First Advertisement for the new system*
4. Evaluation of the detailed concepts and testing if possible	- *Three Sustainability Radars for the three sustainability dimensions with six criteria each*
5. Planning implementation	- *List of specifications for PSS implementation* - *Business plan for new PSS*

Fig. 4. Suggested steps and tools in PSS development (taken with permission from the UNEP publication 'Design for sustainability – A step by step approach'; Crul et al., 2009: 101).

and unexpected PSS combinations without major design and testing needs, hence mitigating the potential high costs of customization of offerings, etc.

- Geng et al. (2011, 2010a,b) suggest yet another PSS design method, emphasizing a formal and quantified assessment of customer requirements (CRs) and engineering characteristics (ECs), using a non-linear optimization approach to decide systematically how levels of product ECs and service ECs in combination maximize fulfillment of customer requirements.
- Clayton et al. (2012) performed a single in-depth exploratory case study of PSS design, which showed that various feedback loops occur in the design process and that it is cyclical and iterative. They interpreted this as deviating from what they perceived as the rather linear approaches in PSS design literature. Pezzotta et al. (2012) therefore suggest a 'spiral' approach to PSS development that has a few iterations in the design process, which leads via various initial attempts to an operational prototype PSS.
- Akasaka et al. (2012) provide a highly formalized PSS design methodology based on research from the field of service engineering. Customer requirements are identified in a highly formal way and PSS designs that meet the requirements are then developed with the help of a Service Design Catalog. The method still lacks an evaluation phase for the generated solutions.

Compared with the pre-2006 literature, essentially this work emphasizes interaction between design of product and service components, design of modular components that can be easily combined to form different PSS, the non-linear and trial-and-error nature of PSS design, and has developed (see Table 7) a host of innovative and sophisticated tools that could support PSS design, for instance with regard to ex-ante customer satisfaction and cost assessments. All these innovations fit in well with the general scheme outlined in Fig. 4 (compare e.g. also Lindahl et al., 2007).[12] Some authors question whether this means PSS design is now mature. Vasantha et al. (2012) evaluated the maturity of eight archetypical PSS design methods with regard to twenty aspects. Among other things, their review suggests a lack of attention to detailed requirement lists, design of the business model in conjunction with the product-service, tools supportive to sustainability, the organization of co-creation processes, and the relevance of differences between domains (B2B, B2C and B2G) and types of PSS in the design process. They also noted important differences in terminology in PSS design methods. Finally, they advocated more on-the-ground evaluations of PSS design in industry.[13] The tools in Table 7 could provide solutions for some of these shortcomings (e.g. requirement lists). It

[12] An exception is probably the 'prototyping' service engineering model suggested by Aurich et al. (2010), which is particularly suitable for PSS that are relatively simple and where the business is so dynamic that a short time to market is essential.

[13] The improvements suggested by Vasantha et al. (2012) would probably lead to much more refined and differentiated methodologies at a much higher level of granularity and detail than those currently depicted in literature. This has pros and cons. The pro is that more tailor-made methods will become available. The con is that at some point each firm will appear so unique that generic methods always have to become tailor-made, and that hence the main question is whether or not generic schemes like the UNEP manual cover the most important aspects in PSS design and help managers in firms to develop their own, more detailed procedures.

Table 7
Some specific tools/contributions to PSS development methods from the post-2006 literature, by topic.

Author(s)	Contribution to methods for PSS development
Visualization methods	
Geum and Park (2011)	Develops a blueprinting approach for PSS visualization, using a highly formalized symbolic language representing activities, decision points, etc.
Lee et al. (2011a, b)	Development of a design template for PSS design and illustrate it with a case study
Lim et al. (2012)	Development of a visualization tool for PSS design, called the PSS board. This is a matrix board where the customer activities, state of the products, services, dedicated infrastructures, and partners are placed in five rows, and nine general PSS process steps in nine columns (Define, Locate, Prepare, Confirm, Facilitate, Monitor, Resolve, Modify, Conclude)
Information feedback systems enabling or informing PSS design	
Mori et al. (2008)	Describes a remote monitoring and maintenance system (with as case machine tools). While not specifically developed in the context of PSS, such remote monitoring can be an enabler for many types of PSS.
Hussain et al. (2012)	Describes how to learn from in-use data and experiences with existing PSS and use them in new or improved PSS design, using a detailed analytical scheme measuring expected system performance and actual system performance
Lightfoot et al. (2011)	Use of ICT and sensoring techniques for real time monitoring of equipment performance as an enabler for offering maintenance and repair services
Assessment of customer satisfaction or needs for PSS design	
Du et al. (2006)	Describes a method to analyze and optimize customer satisfaction in product customization via an explicit requirement analysis of functional attributes and importance, experimenting with design alternatives, assessment of perceived utility of alternatives and an assessment of customization costs.
Matzen and McAloone (2006)	Refines an Activity Modeling Cycle (AMC) model in order to understand customer needs to be addressed in PSS development.[11]
Kimita et al. (2009)	Development of customer satisfaction measurement based on the non-linear value function called the satisfaction-attribute function.
Ex ante economic value evaluation	
Cho et al. (2010)	Development of metrics for ex-ante evaluation in PSS concept design of the economic, environmental and experience value of PSS
Alix and Zacharewicz (2012)	Selection method for PSS design on profitability using a method called Generalized Discrete Event Specification, using simulations including stereotyped client behavior, in a case on product oriented versus use oriented PSS for toys.
Kreye et al. (2009)	Assessment of the Through Life Cycle costs of PSS is pivotal for business decisions, but uncertainties about e.g. required maintenance level make such predictions highly uncertain. The paper proposes game theory to capture such uncertainty.
Datta and Roy (2010); Erkoyuncu et al. (2011)	Review of cost modeling techniques including uncertainty assessment for performance based product-service contracts
Aras et al. (2011).	Economic assessment of optimal inventory and pricing policies for leased products, which after take-back are remanufactured, taking into account factors like willingness to pay for leasing new products, buying remanufactured products, deterioration in age, etc.
De Coster (2011)	Foresight approach for estimating future potential PSS revenues in the telecom sector
Other	
Geum and Park (2010); Geum et al. (2011)	Suggestion to include technology roadmapping to the PSS toolbox to support strategic management of technology, product and service development over time
Datta and Roy (2013)	Suggests an agent-based model with the aim of understanding the cost impact of different incentive mechanisms and risk sharing mechanisms in PSS.
Bianchi et al. (2009)	Proposal for a qualitative system dynamics approach for an ex-ante evaluation of the potential success of PSS.
Sundin and Lindahl (2008), Sundin et al. (2009)	Suggestions for design guidelines supportive to take-back and remanufacturing of products provided via a PSS business model
Bertoni and Larsson (2010)	Bottom-up knowledge sharing techniques supportive to PSS design.
Berkovich et al. (2011)	Evaluates the approach of Requirement Engineering for application for PSS. Requirement Engineering 'comprise [s] the extensive identification of the solving problem in form of requirements and constraints, their management, traceability, and description in an adequate level of detail throughout all development stages'. Existing product, software and service engineering approaches are insufficient for PSS and particularly lack procedures for requirement concretization and change in requirements.

may also be that design methods aimed at improving competitiveness currently dominate, which might explain the lack of explicit attention to sustainability. Contributions to resource-efficiency will obviously then only occur because the business incentives related to PSS (and result-oriented PSS in particular) foster low material use, rather than the fact that the design process is focused on identifying sustainability opportunities per se.

Probably the most interesting contribution of the post-2006 literature is that it focused not only on PSS development per se, but also on the capability development challenge and transformation processes that firms have to deal with to achieve market success with PSS. Such analyses have been performed mainly for B2B manufacturing firms. As the next section also illustrates, this is probably one of the key success and failure factors (see also Cavalieri and Pezzotta (2012); Ryan et al. (2011)). Alix and Vallespir (2010) are among those who have addressed the issue of company fit and integration. They provide a toolbox for evaluating how the requirements for PSS relate to the core competences, processes and environment of a manufacturing firm. Tan et al. (2010, cf. 2007) also reviewed strategies for designing and developing services for manufacturing firms. In two case studies they found that the systematic design methods offered by literature could not be followed directly – the two firms concerned found they had to establish independent customer-oriented organizations so that there was no negative interaction with existing (product-oriented) businesses and actors in the market. An alternative for this identified by other authors is to team up with another firm that is responsible for providing the service component. Hence, various authors focus on methods of partner selection and building and evaluating collaborative networks (Zhang et al., 2012; Sun, 2010), which is only the first step in establishing a properly functioning PSS supply chain in which all the partners share relevant information, have aligned incentives, and experience balanced benefits (Lockett et al., 2011).

Baines et al. (2009b) analyze the organizational implications of servitization for firms. A limitation of this work is that it is based on a single, confidential case study of a firm producing high value capital equipment for the power, defense and aerospace markets, although the authors argue that the findings are generally applicable for B2B manufacturing firms. The delivery system will tend to be configured around product assembly. Test and repair capabilities will be located near clients. Response times will be short. Internal structures must be cross-functional. Planning and control will optimize product availability for clients. Product ranges will be limited but complemented by a broad differentiation of service

bundles. Employees must have both product knowledge and customer and relation management skills. As further elaborated by Baines et al. (2011), servitizing firms tend to retain capabilities in design and production (rather than outsourcing them), since that benefits the speed and effectiveness of their response while minimizing costs. Datta and Roy (2011) focus on the operational strategy for delivery of performance-based services and found that key success factors were an integrated customer-service provider team, understanding the customer's processes and inventory ordering patterns, and effective contract design, including linking the customer's responsibility to the contractual KPIs. Johnstone et al. (2009) noted in a case study from the aerospace industry that seamless integration of product and service components and creating an organization-wide service culture were both essential and a major challenge. They further noted that where divisions of firms first independently produce service offerings for their specific markets, top-down management attention has to follow to ensure improved co-ordination across divisions. Martinez et al. (2010) managed to condense this to an "'architecture of challenges in servitization", whose dimensions are an embedded product-service culture, delivery of integrated offerings, internal processes and capabilities, strategic alignment and supplier relationships.

3.4. Business and environmental (dis)advantages of PSS

3.4.1. Literature from 2006 and earlier

In our reviews from 2004 to 2006 (Tukker, 2004; Tukker and Tischner, 2006a) we used Stewart's concept of Economic Added Value (1991) to identify crucial elements determining the business advantages and disadvantages of PSS. We based our reviews on the simple assumption that the aim of business is to remain profitable for a sustained period of time. I list those elements below, where relevant enriching the analysis with other references from the period up to 2006:

1. Market value of the PSS compared to the competing product. In this context, it is essential to distinguish between tangible and intangible value. Tangible added value consists of the resources, time input and cost of capital that the user saves compared with using a product-based solution. PSS are indeed often cheaper for the user in a traditional sense. Intangible added value relates to 'priceless' experiences, brand value, sense of control, ease of access, etc. and is often forgotten in a comparison between PSS and product.[14] In this respect, many PSS, particularly in the B2C area, score worse than the competing product solution – car or washing machine ownership has intangible added value in terms of self-esteem, access, etc.
2. Production costs of the PSS compared to the competing product. These include traditional costs such as the input of resources and labor required to create the PSS. However, PSS often involve additional cost items that product manufacturers are less familiar with. An example is transaction costs, since a PSS is usually delivered by a group of companies, resulting in more complicated contracting and revenue-sharing schemes. And PSS producers suddenly assume greater responsibility for delivering a result for a considerable time for a pre-agreed price; if there are cost factors that are unknown and cannot be influenced over time, this can generate a significant cost risk that does not arise in a simple product sales model.
3. Investment needs/capital needs for PSS production. This consists of two factors. First, a PSS provider often has to finance the capital costs of the solution (e.g. a leased car) and is paid back in installments. However secondly, and probably more importantly, most companies start out with experience as purely a product or a service provider and need either to develop or buy in entirely new competences and capabilities. On top of this, the PSS business may need new delivery and supply channels and production practices that could compete with the existing product sales business, leading to depreciation of capital and goodwill.
4. The ability to capture the value present in the value chain, now and in the future. Often, PSS helps a business to establish a more strategic position in the value network, enabling it to capture more value. Since the relationship with the client is not confined to the moment the product is sold, but is a more sustained relationship, PSS typically lead to higher client loyalty and more dedicated and unique knowledge about clients and consequently, greater potential to innovate.

In a highly cited review based on a survey of new business developers, De Brentani (2001) highlighted the company-internal factors already briefly mentioned under point 2 above. Success factors for novel service development include: ensuring an excellent customer/need fit, involving expert front-line personnel in creating the new service and in helping customers appreciate its distinctiveness and benefits, and implementing a formal and planned launch program for the new service offering. Essentially, his findings emphasize well-known factors such as the need for the offering to have added value for customers and that a well-planned development process is essential for a successful project. De Brentani further identified other factors that depend on whether the new service development was incremental or radical, and which echo other business literature (e.g. Hamel and Prahalad, 1994) and more recent work from the field of sustainable system innovations (e.g. Christensen, 1997; Elzen et al., 2004; Tukker et al., 2008).

- Incremental service innovation: the success factors here are using a strict gate-stage development process at the front end and design phase; ensuring that differentiation from competitors does not come at a high cost or make the offering too complex; and ensuring a good 'fit' with the firm's existing unique competencies, experiences and reputation.
- Radical service innovation: a key success factor here is a corporate culture and visionary leadership and mentorship that encourages entrepreneurship and creativity and supports striving for 'stretch'. A good market potential and marketing capabilities are also far more essential for making such essentially novel offerings successful than in the case of incremental innovations.

As for environmental benefits, our own review and others from that period showed a mixed potential (Tukker, 2004; Tukker and Tischner, 2006b).

[14] For instance, in the strictly function-oriented approach of Life Cycle Assessment, which compares the environmental impacts between products providing the same functionality. Many LCAs see the functionality of cardboard packaging as equal to that of glass packaging, whereas for wine drinkers it is clear that drinking from a bottle provides a much better experience than drinking the same wine packed in a carton and hence they do not provide the same intangible functionality. Komoto et al. (2005) provide an interesting simulation of the life cycle costs of washing in different service provision scenarios (machine owned by the user; 'pay per wash' functional sales with the machine placed at the user; shared use of a machine between households; and outsourcing washing to a commercial provider). However they also flag that these options have quite different 'experiences' or 'intangible' value – the commercial model, for instance, implies a need for better planning of when to have clothes washed. It is essential to take these less quantifiable value aspects into account. Mont (2004b) also found similar trade-offs between costs, environmental impacts, and consumer experience in evaluating PSS for lawnmowers and drills, where in her cases the environmental benefits of the PSS prevailed.

- Product-oriented services would leave the system largely as is and would at best produce some environmental gains through better maintenance, which might lead to optimal energy and resource use in the use stage, for example. However, the business incentive is still to sell as many products as possible, and limited improvements of resource-efficiency could be expected. Indeed, manufacturers might have the incentive to create 'built-in obsolescence' in order to sell replacement products sooner (Slade, 2007).
- Use-oriented services were found to constitute a mixed bag. Leasing often leads to less careful behavior by the user since he or she no longer owns the product, probably leading to higher impacts. Product renting and sharing, and particularly pooling, have significant benefits, however, since the capital goods are used more intensively, and, in the case of pooling, impacts in the use stages are shared by more than one user. Heiskanen and Jalas (2003) show, for instance, that car sharing reduces impacts by 30–50%, as do ski rental services. Drilling rental services can reduce impacts by as much as a factor of 10. Laundry services would be up to 50% more energy and water efficient.
- Result-oriented services, finally, would in theory have the greatest potential for environmental improvement, since solutions could be offered that are based on approaches that are entirely different to the existing product concept. In result-oriented business models, the use of materials also becomes merely a cost factor – using more materials or creating more products does not lead to increased revenues. Hence, in principle there is an incentive to reduce the costs of materials by using fewer, using them longer, etc. Such gains are not a given, however – for instance, outsourcing of catering while still offering the same menu will at best yield limited improvements in terms of to efficiency gains.

In essence, one cannot therefore expect product-oriented PSS to provide a radical boost in terms of resource-efficiency or a circular economy. The potential for use-oriented and result-oriented PSS is higher, but here we see in various case studies that diffusion of PSS on the market may be hindered due to the problems described above. Besch (2005) works this out for rental of office furniture, which should, in theory, be more cost-effective than buying since furniture that is no longer needed can be used again by others. Problems identified by Besch include no apparent benefits for business compared to the 'sales' model, and people may only want to rent 'in fashion' designs, which creates uncertainty about whether products will be rented long enough to pay off the costs. As discussed in Tukker and Tischner (2006a), products for which a PSS business model will work are typically expensive, technically advanced, requiring maintenance and repair, easy to transport, used infrequently by customers, and not heavily influenced by branding, fashion, etc. There is also a clear difference in the success of PSS between the consumer and business markets – consumers attach far greater value to owning the products they use and having full control over how to use them. It is therefore not surprising that various authors argue convincingly that legal and political changes are essential if sustainable PSS are to break through in the market, for example, to realize fair trade and attain recycling and remanufacturing goals (Michelini and Razzoli, 2004b).

3.4.2. Literature from 2006 and later

The literature addressing the advantages of PSS for business and in terms of sustainability since 2006 consists of case studies, sector reviews, and more comprehensive reviews of PSS performance. It has to be said, however, that as in the pre-2006 period, case studies and qualitative assessments dominate. Research methods such as surveys, statistical data analyses, and meta-reviews analyzing quantitative data from case studies are still very rare, although they are needed to gain a quantitative insight into the sustainability and business benefits of different PSS at societal level. Some relevant case-study and sector-level contributions to the body of knowledge from this literature include the following.

- Halme et al. (2006) evaluated 200 potential 'home services', i.e. PSS related to the home. They found that many would in principle be cheaper and comfortable but nevertheless did not appear to have been widely implemented. They mention various factors hindering their diffusion: particularly for consumers, ownership adds to the intangible added value; firms often have no interest in changing to a PSS-like business model since a) it requires an entirely different skill set and business chain and b) it requires a total redesign of the business model, probably an early write-off of production equipment (since product life will be extended or products will be used more intensively), etc. They also did not find a clear reduction of material intensity with a switch to PSS.
- Williams (2007) gives an example of the introduction of PSS in the automotive industry. His analysis confirms that particularly use-oriented and function-oriented PSS require significant changes in ownership structure, infrastructure and institutional context. There are therefore likely to be significant barriers to implementing such PSS.
- Devisscher and Mont (2008) showed that shared use of equipment by smallholder coffee producers in Bolivia in a cooperative set-up resulted in significant economic and environmental advantages. Via shared use more efficient equipment became affordable, leading to better coffee quality, market opportunities and income. It led to time savings in production and reduction of intensive labor, as well as more professional management of solid and liquid waste flows. Barriers included capital availability for the cooperative, a relatively old and inflexible population running the individual farms, and the fact that the members of the cooperative were not obliged to trade via the cooperative.
- Kuo (2011) presented an interesting case study concerning a company in Taiwan that provides document equipment, solutions and services, with copying equipment playing a central role. It found that a major advantage of a procurement model over a rental model was lower system costs due to the fact that the customer who owns a product uses it more carefully.
- Haapala et al. (2008) showed that home washing is 85% cheaper than using a washing service due to the elimination of labor costs and overheads but can have up to 50% more environmental impacts. Agrawal et al. (2012) compared the environmental advantages and disadvantages of leasing and selling. They reached mixed conclusions: leasing may give firms an incentive to design more durable products, but also to remove off-lease products from the market to avoid cannibalization.
- Intlekofer et al. (2010) performed a life cycle optimization analysis of two product categories (household appliances and computers), comparing leasing with product sales. They arrived at a classic conclusion: products with high impacts during the use phase and for which the technology is improving can benefit from reduced life cycles (since energy-intensive appliances will then be replaced by less intensive appliances, which yields energy benefits higher than the energy costs in production), whereas products with high manufacturing impacts and no improvements in technology should instead be designed for long lifetimes. Leasing could support both strategies, but the authors also note that consumers 'prefer to buy new products after only a few years of use'.

While the post-2006 literature may have produced some more refined frameworks for evaluating sustainability and competitiveness (e.g. Roy and Cheruvu, 2009), this more recent literature seems to confirm the findings of the pre-2006 literature. The examples above confirm that product-oriented and use-oriented PSS, in particular, are not by definition more resource-efficient than business models based on product sales, as reflected by the statements of Haapala et al. (2008) regarding the removal of off-lease products from the market and Kuo (2011) on the less careful user behavior when products are leased and rented. Furthermore, PSS can have benefits for businesses or consumers, but certainly not in every instance. Various examples confirm the significant difference between business-to-business and business-to-consumer markets – consumers appreciate ownership and control (Halme et al., 2006), possessing new, 'in fashion' products (Intlekofer et al., 2010), and easy access to the product (Williams, 2007).

In short, the analytical framework for business value presented earlier is in fact confirmed, stipulating that it is essential to analyze consumer added value (e.g. Halme et al., 2006; Intlekofer et al., 2010), various factors (risks, transformation barriers) influencing production and investment costs (e.g. Kuo, 2011; Williams, 2007; Haapala et al., 2008; Devisscher and Mont, 2008), as well as continuous value capturing potential. We see these findings reflected in more generic papers and analyses, such as:

- Bankole et al. (2012), who consider PSS to be a competing and stable offering if it is 'affordable' from the perspective of the customer (affordability), manufacturer (profitability) and supplier (sustainability);
- Mo (2012), who argues that the PSS provider takes considerable risks, not only in the manufacture of the product itself, but also with regard to service provision for a long time at a predetermined price. This finding is echoed by Datta and Roy (2013), who indicated that outsourcing of high risk, complex tasks is unlikely to result in gains in quality and costs;
- Neely (2009), who performed a meta analysis of the success of PSS business models, analyzing data from some 10,000 firms included in the so-called OSIRIS database. He discerned some 12 categories of servitization, building upon the well-known classification of product-oriented services, use-oriented services, and result-oriented services, adding integration- and service-oriented PSS. He found that servitized manufacturing firms are larger than product-oriented firms but have lower profit margins. He also found that a larger than average number of servitized firms went bankrupt, suggesting that servicitizing is not without risk.

In sum, it has to be concluded that PSS will not by definition be more resource-efficient or 'circular' than product systems – result-oriented PSS offering the greatest prospect of radical resource-efficiency gains. Nor will PSS by definition be a business success, so companies that perform best in identifying those cases where PSS has added value and how it can best be implemented will be most successful. Other firms will either miss interesting business opportunities or bet on the wrong PSS in the wrong markets and develop them via sub-optimal processes. The most interesting literature, therefore, is probably work that elaborates on the analyses of De Brentani (2001): what factors can help in understanding why and how companies can have success in PSS development. This was also found to be the most relevant remaining research question in the thorough review of PSS by Baines et al. (2009), as well as in other research (e.g. Satao and McAloone, 2011). How should PSS design take place in the context of an industrial organization? What should be the company's organizational strategy? How should firms make the transition to a servitized operational strategy?[15] Brown et al. (2011) analyzed the success factors for B2B companies in servicizing their offerings and found that well-regarded brand reputations, relevant service competencies, and strong buyer–seller relationships were relevant. In addition, shared innovativeness, an ability to enhance utility and/or create transaction efficiencies, and effective marketing support enhance the chance of success. Companies must therefore already have the basic 'stretch' and 'learning' capability to be successful (c.f. Hamel and Prahalad, 1994). These conclusions are not fundamentally different from those arrived at earlier by De Brentani (2001).

4. Conclusions: progress in the PSS field and reflection on the theme of this special issue

To conclude, we see that research in the field of PSS is progressing well. The number of papers published annually has more than quadrupled in the last decade, whereas the number of scientific publications in general has only doubled. Where research labeled as PSS started out in Europe, it is now clearly embedded in the research infrastructure in a number of Asian countries. PSS is a subject that is now also discussed in a variety of research fields, i.e. as well as researchers interested mainly in sustainable design, also by researchers involved in engineering design, business management and information systems. Obviously, this has made the field more complex, since these communities each tend to have their own focus and vocabulary, but at the same time it ensures that the topic of PSS is now researched from different perspectives and that there is less chance of 'blind spots' occurring.[16] Most reviews now tend to contain analyses embracing the whole range of disciplines (e.g. Boehm and Thomas, 2013).

As for research into the concept of PSS, PSS development methods, and the economic and environmental potential of PSS, the body of research since the reviews performed around 2006 has clearly contributed additional insights. It seems, however, that progress, and the remaining research needs, differ depending on the topic:

1. PSS conceptualization and terminology. The literature since 2006 has clearly come up with more refined definitions, subclassifications, and dimensions that characterize PSS (e.g. Lay et al., 2009). It is telling, however, that the highly formalized and strongly analytical approach taken by Boehm and Thomas (2013) to assess the common ground across most definitions led to the following proposal: '*A Product-Service System (PSS) is an integrated bundle of products and services which aims at creating customer utility and generating value*'. It is of course valuable that a quantitative method was used to identify this definition as the best common ground in the scientific literature. Yet, it is also clear that this definition scarcely differs from those developed before 2006, which suggests that at a general level the conceptualization of PSS had already become quite mature by then. The same can probably not be said of the more detailed terminology and vocabulary used within the PSS community, however. Vasantha et al. (2012) discerned a clear need to define

[15] Note that these questions go considerably further than the PSS development methodologies described in the previous section. These are questions about the firm's internal capabilities, performance and strategy, which appear to be pivotal for PSS success.

[16] such as the finding of Tukker and Tischner (2006b) that the PSS concept as it developed within the sustainable design community before 2006 took hardly any notice of the quite relevant literature on business modeling.

a common ontology for aspects such as characteristics of requirements, product services, stakeholders, (steps in the) design processes, life-cycle stages, outcomes, business models and support systems. This is probably not so much a question of doing more research but rather embarking on a standardization process in the PSS community.

2. PSS design methodologies. Here too we see that the literature after 2006 managed to refine and specify the methodologies that had already been developed before 2006, still largely following the (apparently robust) existing framework of analysis/idea generation, selection and refining/and implementation. Important new suggestions include proposals to accelerate PSS development and make them more versatile by using a modular design approach (e.g. Aurich et al., 2006b), as well as a host of suggestions for specific tools that could be used (such as applying requirement engineering, various economic optimization techniques, technology roadmapping to understand PSS development over time, and the use of information feedback systems enabling or informing PSS design). Some authors claim, however, that integration of such tools in the main detailed PSS design methods that are available is not yet mature or that tools are still lacking, potentially leading to a lack of emphasis on requirements that should drive PSS design, how to organize co-creation processes, sustainability opportunities, and the relevance of differences between domains (B2B, B2C and B2G) and types of PSS in the design process. This, together with more on the ground experimentation and evaluation of PSS design in different industries, should form the research agenda moving knowledge on PSS design forward. The most important contribution of the post-2006 literature is probably the strong attention to what PSS development means for a company's structure, culture, capabilities and management. Examples are a focus on product availability for clients rather than product production; an emphasis on diversification through services rather than product ranges; and the need for staff to possess both product knowledge and relation management skills. This, probably much more than having a sound design method, is currently the key success factor, particularly for product-oriented companies that want to put PSS on the market (cf. Baines et al., 2007, 2009a).
3. Business and environmental (dis)advantages of PSS. Here, recent literature – mainly case study research – simply seems to confirm the findings of the pre-2006 literature and the framework presented in Section 3.4. PSS is not the sustainability panacea. Renting, leasing and sharing can have environmental benefits since, in principle, the same service level can be achieved with the use of fewer artifacts. However, leased products tend to be used less carefully than products that are owned, and rented, leased or shared products may be returned earlier to the service provider in comparison to the lifetime of a product sold in the traditional manner. Furthermore, the added value of PSS in terms of comfort, convenience and the experience of ownership, particularly in a B2C context, might be lower than that of a corresponding product. Consumers simply value owning things and having control over artifacts, issues that seem less relevant in a B2B context. For some firms, the costs of the transition from product-oriented to PSS-oriented can be prohibitive, particularly for result-oriented PSS requiring a totally different skill set and organization than in the case of product sales. Due to the high labor intensity, PSS can be more expensive than having a product operated by a consumer. High speeds of innovation make re-use impossible and undermine the economic potential of taking back products or components under leasing or pay-per-unit-use contracts. It is striking, however, that quantitative research methods like surveys, statistical data analyses, and even meta-reviews analyzing quantitative data from case studies are still rarely applied. Such research is recommended for the future, since it is essential to have a quantified and detailed understanding of the economic and other benefits of different PSS in different markets for competitiveness and sustainability.

This last point, then, also provides an answer to two key questions that play a central role in this paper and special issue, respectively. The first question is to what extent sustainable PSS can contribute to resource-efficiency and a circular economy. Product-oriented PSS do not change the incentive to maximize product sales. Use-oriented PSS potentially intensify the use of material products and hence could reduce the need for materials, but a possible drawback is that they could prompt less careful use, leading to quicker wear and tear. Result-oriented PSS have the greatest potential and provide an incentive to reduce material costs but require the most radical change in the business model compared with product sales, which hampers their broad implementation and hence real contributions to resource-efficiency and circularity.[17] This then leads to the second question, related to level of diffusion, which plays the central role in this special issue: *'Why have sustainable Product-Service Systems not been widely implemented?"* In our view, the answer simply remains the same as the one given around 2006. Certainly, in various cases PSS can provide higher tangible and intangible value to the user, can be created with lower system costs, and can improve a firm's position in the value chain – and hence its competitive advantage. However, as we already concluded in 2006 (Tukker and Tischner, 2006a):

> *"...PSS do not deliver such bonuses by definition. Particularly in a B2C context, product ownership contributes highly to esteem and hence intangible value. Access to the product is [in PSS] often more difficult, creating tangible consumer sacrifices. Costs can be higher, if the PSS has to be produced with higher priced labour or materials, or when the often more networked production systems generate high transaction costs. And sometimes a switch to PSS may weaken the position in the value chain. In industries where excellence in product manufacturing and design form the key to uniqueness and hence power in the value network, diverting focus to an issue such as PSS development is a recipe to lose rather than win the innovation battle."*

In our view, the limited diffusion of sustainable PSS, in particular, such as car sharing systems, shared use of do-it-yourself tools, and washing services, can be explained simply by the factors mentioned in the above quote. Particularly in B2C markets, time and again it has been found that one of the most valued issues for consumers is to have control over things, artifacts, and life itself (cf. Stø et al., 2008; Kahneman, 2011). It will never be easy for a PSS provider to overcome the perception that he is putting his consumer in a relatively dependent position or influencing, or even prescribing, how his consumer should behave. Supportive policies may be able to help diffusion of PSS (e.g. Ceschin and Vezzoli, 2010), but this is unlikely to be a productive way forward if customer experience of PSS is truly much lower than for the competing product. Conversely, stimulating wider diffusion of PSS would be supported by designs that enhance rather than limit customer experience and, from the firm's perspective, by improved insights into how the risks from a transition from a product-centered firm to a PSS-centered firm can best be managed. It is indeed on this point (number 2 in the list above) that most progress has been made in

[17] As indicated, this finding does not differ from the pre-2006 literature.

the PSS literature since 2006. This seems pivotal for realizing a true circular economy and/or a resource revolution via the implementation of PSS.

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