POLITECNICO DI TORINO
Repository ISTITUZIONALE

Research on product-service systems: topic landscape and future trends

Original
Research on product-service systems: topic landscape and future trends / Barravecchia, F., Franceschini, F., Mastrogiacomo, L., Zaki, M.. - In: JOURNAL OF MANUFACTURING TECHNOLOGY MANAGEMENT. - ISSN 1741-038X. - STAMPA. - 32:9(2021), pp. 208-238. [10.1108/JMTM-04-2020-0164]

Availability:
This version is available at: 11583/2905588 since: 2021-06-10T08:43:45Z

Publisher:
Emerald

Published
DOI:10.1108/JMTM-04-2020-0164

Terms of use:

This article is made available under terms and conditions as specified in the corresponding bibliographic description in the repository

Publisher copyright

(Article begins on next page)

16 June 2026

The current issue and full text archive of this journal is available on Emerald Insight at:
https://www.emerald.com/insight/1741-038X.htm

Received 23 April 2020
Revised 12 August 2020
26 October 2020
2 February 2021
18 April 2021
Accepted 25 April 2021

Research on product-service systems: topic landscape and future trends

Federico Barravecchia, Fiorenzo Franceschini and Luca Mastrogiacomo
DIGEP (Department of Management and Production Engineering), Politecnico di Torino, Torino, Italy, and
Mohamed Zaki
Department of Engineering, Institute for Manufacturing, University of Cambridge, Cambridge, UK

Abstract

Purpose – The paper attempts to address the following research questions (RQs): RQ1: What are the main research topics within PSS research? RQ2: What are future trends for PSS research?
Design/methodology/approach – Twenty years of research (1999–2018) on product-service systems (PSS) produced a significant amount of scientific literature on the topic. As the PSS field is relatively new and fragmented across different disciplines, a review of the prior and relevant literature is important in order to provide the necessary framework for understanding current developments and future perspectives. This paper aims to review and organize research contributions regarding PSS. A machine-learning algorithm, namely Latent Dirichlet Allocation, has been applied to the whole literature corpus on PSS in order to understand its structure.
Findings – The adopted approach resulted in the definition of eight distinct and representative topics able to deal adequately with the multidisciplinarity of the PSS. Furthermore, a systematic review of the literature is proposed to summarize the state-of-the-art and limitations in the identified PSS research topics. Based on this critical analysis, major gaps and future research challenges are presented and discussed.
Originality/value – On the basis of the results of the topic landscape, the paper presents some potential research opportunities on PSSs. In particular, challenges, transversal to the eight research topics and related to recent technology trends and digital transformation, have been discussed.

Keywords Product-service systems, Text mining, Latent dirichlet allocation, Topic landscape, Literature review

Paper type Literature review

1. Introduction

The last two decades have seen a growing trend toward research on product-service systems (PSSs). One of the first definitions of the concept was provided by Goedkoop *et al.* (1999) who stated that PSSs are "systems of products, services, networks of "players" and supporting infrastructure that continuously strives to be competitive, satisfy customer needs and have a lower environmental impact than traditional business models". The following year, Roy

Journal of Manufacturing Technology Management
Vol. 32 No. 9, 2021
pp. 208-238
Emerald Publishing Limited
1741-038X
DOI 10.1108/JMTM-04-2020-0164

© Federico Barravecchia, Fiorenzo Franceschini, Luca Mastrogiacomo and Mohamed Zaki. Published by Emerald Publishing Limited. This article is published under the Creative Commons Attribution (CC BY 4.0) licence. Anyone may reproduce, distribute, translate and create derivative works of this article (for both commercial and non-commercial purposes), subject to full attribution to the original publication and authors. The full terms of this licence may be seen at http://creativecommons.org/licences/by/4.0/legalcode.

Funding: This work has been partially supported by "Ministero dell'Istruzione, dell'Università e della Ricerca" Award "TESUN-83486178370409 finanziamento dipartimenti di eccellenza CAP. 1694 TIT. 232 ART. 6".

(2000) published one of the early works on this topic, highlighting the positive environmental impacts that arise from the cohesive delivery of products and services.

Since its first appearance, the meaning of the term PSS has evolved and broadened (Hansch Beuren and Cauchick Miguel, 2013). Some common features emerge from definitions available in the literature:

(1) PSSs are value offering composed of a mix of tangible and non-tangible elements, that can be labeled as products, services and infrastructures (Goedkoop *et al.*, 1999; Barravecchia *et al.*, 2020a, b);

(2) the elements of a PSS interact to fulfill customer needs (Manzini and Vezzoli, 2003);

(3) PSS-based strategies have positive environmental effects compared to traditional business models (Roy, 2000);

(4) Interactions between provider and customers are extended to different phases of PSS lifecycle (Cavalieri and Pezzotta, 2012).

Even if relatively young, this field of research has produced a remarkable amount of scientific literature that analyzed the PSS concept from a plurality of points of view. Despite this, the literature still remains sparse in terms of guidance on how to categorize and delineate studies on PSSs (Li *et al.*, 2020). Research on PSS is becoming increasingly fine-grained and some fundamental aspects of PSS remain dispersed (Annarelli *et al.*, 2016). Multiple disciplines are interested in the concept of PSS (Mont and Tukker, 2006). Each of these analyzes the PSS from its specific point of view, sometimes losing the overall view of the phenomenon. This conclusion is proven by the wide diffusion of literature reviews related to specific domains such as design (Qu *et al.*, 2016), business models (Reim *et al.*, 2015), or service engineering (Cavalieri and Pezzotta, 2012), while, there is a lack of updated reviews concerning the whole PSS corpus literature (Moro *et al.*, 2020). Heterogeneity in dealing with problems related to PSS enriches the field of research, but at the same time it is likely to lose a comprehensive view of the phenomenon.

A field of research that is becoming increasingly mature and specialized needs a general framework to collocate the different scientific contributions. Considering this, a structured and objective analysis allowing us to understand the main pillars of the PSS literature could be helpful.

The presented research aims at applying a computational and replicable approach to build on existing literature a theoretical framework capable of framing past, present and future works in PSS research. The methodological approach taken in this study is based on topic modeling analysis so as to produce a clustering of the entire body of literature on PSS. Specifically, the Latent Dirichlet Allocation (LDA) algorithm was implemented. This approach provides different advantages, including (1) the capability of analyzing a vast number of papers time, (2) the possibility of automatically grouping scientific articles in homogeneous clusters, thus identifying a framework of the main topics in a specific research field, (3) the outputs are not influenced by bias or prior knowledge of the researchers being produced solely by data analysis (Antons and Breidbach, 2018; Asmussen and Møller, 2019).

In detail, the following two research questions (RQs) were faced up:

RQ1. *What are the main topics within PSS research?* Specific research goals are the recognition and characterization of the main streams of research within the heterogeneous scientific literature on PSS to establish a framework capable of describing the hidden structure of the PSS research corpus.

RQ2. *What are future trends for PSS research?* A specific research goal is the recognition of current and future research priorities to address the academic community's efforts.

Trying to answer these questions, this paper provides the following three main contributions: (1) it proposes a conceptual framework – i.e. a topic landscape – to support identifying and understanding topics and trends in PSS research over the last 20 years, (2) it provides an updated overview of issues discussed in PSS literature and (3) it identifies and analyses emerging trends and possible research directions related to PSS.

Moreover, this study represents a first attempt to leverage machine learning and text mining techniques to cluster scientific contributions on PSS and identify the main research topics.

The rest of the paper is organized as follows. Section 2 presents the methodology applied to produce the topic landscape. Section 3 illustrates the results of the topic landscape of the literature on PSSs. The description of each PSS research topic, including the related literature, is presented in section 4. Section 5 proposes potential opportunities and future trends in PSS research. The concluding section summarizes the implications, limitations and original contributions of the paper.

2. Mapping the structure of the PSS literature

In order to interpret a corpus as vast as that concerning PSS, the first step is to understand its structure. To this end, one of the challenges to be faced when attempting to analyze the scientific production of a large research field is the identification of the most discussed topic. Online databases make available a massive amount of journal articles and conference proceedings. In managing such a large number of documents, traditional methods, based on a systematic reading and classification of the documents, show some limitations, mainly related to the huge need of time and resources (see Table 1).

Trying to overcome these limitations, this study proposes the use of a topic modeling algorithm to identify the hidden structure of PSS literature.

	Method	
	Reading	Topic modeling
A. Assumptions		
Categories are known	Yes/No*	No
Relevant text features are known	No	Yes
Mapping is known	No	No
Coding can be automated	No	Yes
B. Costs		
Pre-analysis costs		
Person-hours spent conceptualizing	Low	Low
Level of substantive knowledge	Moderate/ high	Low
Analysis costs		
Person hours spent per text	High	Low
Level of substantive knowledge	Moderate/ high	Low
Post-analysis costs		
Person-hours spent interpreting	High	Moderate
Level of substantive knowledge	High	High

Note(s): *Yes, when the analysis is based on a pre-defined framework; No when a new theoretical framework needs to be developed

Source(s): Adapted from Asmussen and Møller (2019)

Table 1. Comparison between alternative literature survey methodologies

Topic modeling is unsupervised machine-learning algorithms that can discover topics running through a collection of documents and annotating individual documents with topic labels (Blei *et al.*, 2003). In this research, a specific topic modeling algorithm, i.e. Latent Dirichlet Allocation (LDA), has been applied. Given a big set of documents, LDA handles with the problems of: (1) identifying a set of topics that describe a text corpus (i.e. a collection of text document from a variety of sources); (2) associate a set of keywords to each topic and (3) define a specific mixture of these topics for each document (Blei *et al.*, 2003).

The main difference between topic modeling techniques and traditional literature analysis lies in the cluster identification process (Asmussen and Møller, 2019). Text mining techniques use the information related to the analyzed documents as a whole and cluster the various documents according to their content. From this perspective, this methodology can be defined as a *bottom-up* approach since the clustering is exclusively based on data analysis without any influence from the expert perceptions and prior knowledge. On the contrary, traditional literature survey methodologies can be considered as *top-down* approaches since the classification of papers is based either on pre-existing frameworks or on logical and deductive processes driven by an expert.

Table 1 offers a summary of the differences in terms of assumptions and costs between traditional literature review methodologies based on article reading and the topic modeling approach. The main differences relate to the automation of the process and the required to instruct and perform the analysis. In addition, there is evidence that the topic modeling approach allows even researchers with low substantive knowledge of the field under analysis to address the pre-analysis and analysis phases.

In detail, the LDA methodology can be structured in four steps: (1) identification of the text corpus; (2) text-corpus pre-processing; (3) topic extraction and (4) topic labeling and validation (see Figure 1). The following sections describe the four aforementioned steps in the specific application case related to the review of the PSS literature.

2.1 PHASE I: identification of the text corpus

The first step in the analysis was the selection of the data source. According to a plurality of authors, Scopus proved to be the bibliometric databases with the highest coverage in engineering and management literature in terms of indexed journals and conference proceeding (Harzing and Alakangas, 2016). Data used for our analysis were retrieved from Scopus in January 2020 (Scopus Elsevier, 2020).

This study focuses its analysis on the literature related to the concept of PSS. Similar concepts such as "Solutions" or "Hybrid offerings" were not explicitly included. The primary difference between PSS and similar concepts lies in their origins and in the different research

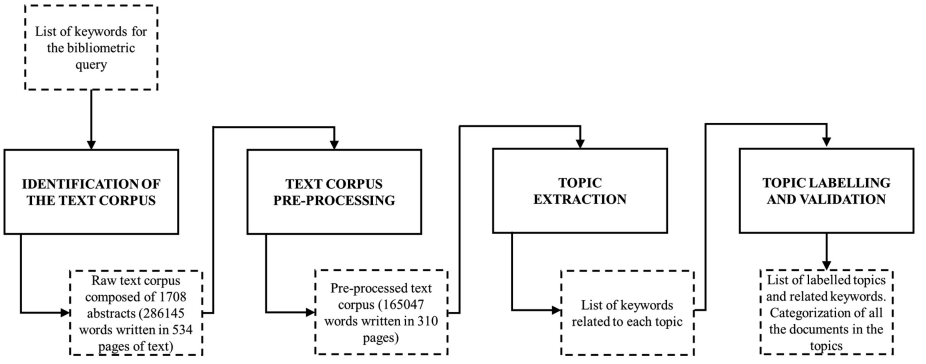

Figure 1.
Methodology of analysis of the PSS literature corpus

communities investigating them. PSS is highly related to manufacturing and engineering research (see Table 2), while other concepts are mainly associated with marketing or service science (Ulaga and Reinartz, 2011). Moreover, the PSS concept has been associated with the positive impact that it can have on the environmental sustainability of production systems. This aspect is marginal in the scientific literature concerning "hybrid offerings" or "solutions" concepts.

In this view, the main inclusion criterion for article selection was the presence in the title, abstract or keywords of the words "Product-Service Systems". Analogous notations were also included in the query. The selection of search keywords is consistent with the objective of the paper, which, as mentioned above, is limited to surveying the literature regarding the specific concept of PSS. The resulting query string was: "PSS" OR "PSSs" OR "Industrial product service system" OR "Industrial product service systems" OR "Product Service Systems" OR "Industrial Product Service System" OR "Product-Service Systems" OR "Product/Service-Systems" OR "IPS2" OR "IPSS". The differences in PSS notation are due to the different origin and academic backgrounds of the authors. In addition, a reference dictionary and standardized definitions have yet to be defined.

Only articles published in scientific peer-reviewed journals and indexed conference proceedings were included in the analysis. This selection resulted in 2028 documents published from 1999 to December 2019, of which 843 were published in journals and the rest on conference proceedings.

Table 2 reports the ten most influential journals in PSS research in terms of the number of published articles. From the table, it can be seen that PSS research covers several domains. In particular, the most critical subject categories in PSS publications are "Engineering", "Business, Management and Accounting", "Computer Science", "Environmental Science" "Energy" and "Decision Sciences".

Given the limited number of articles published, some strongly influential journals on PSS research are not included in the list reported in Table 2. Among these, the most prominent are: International Journal of Operations and Production Management; Proceedings of the

Table 2.
Most influential peer-reviewed journals concerning PSS research in terms of number of published articles. Subject categories were extracted from Scopus database

Title of the journal	Subject categories
Journal of Cleaner Production	(1) Business, Management and Accounting (2) Engineering (3) Environmental Science (4) Energy
Journal of Manufacturing Technology Management	(1) Business, Management and Accounting (2) Engineering (3) Computer Science
International Journal of Production Research	(1) Business, Management and Accounting (2) Decision Sciences (3) Engineering
CIRP Journal of Manufacturing Science and Technology	(1) Engineering
Computer Integrated Manufacturing Systems	(1) Engineering
International Journal of Advanced Manufacturing Technology	(1) Engineering (2) Computer Science
CIRP Annals - Manufacturing Technology	(1) Engineering
Computers in Industry	(1) Engineering (2) Computer Science
Production Planning and Control	(1) Business, Management and Accounting (2) Decision Sciences (3) Engineering (4) Computer Science
International Journal of Product Lifecycle Management	(1) Business, Management and Accounting (2) Engineering (3) Decision Sciences

Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture; CIRP Annals - Manufacturing Technology; Industrial Marketing Management.

As for most of the applications of LDA in the analysis of scientific literature, the collection of the abstract of the documents was used as text corpus for the analysis (Fang *et al.*, 2018). This phase resulted in the definition of the initial dataset of 534 pages of raw text composed of 286,145 words.

2.2 PHASE II: text corpus pre-processing

Following the approach suggested by Meyer *et al.* (2008), the text corpus was pre-processed and unified in order to improve the efficiency of the topic modeling algorithm. In detail, the pre-processing phase included the following main steps:

(1) Removal of stop words (e.g. "the", "and", "when"), punctuation, numbers, words with a low frequency, words generally not related to topical content (e.g. "paper", "present");

(2) Text lemmatization, i.e. all the words with similar meaning but with different inflected forms were replaced with a unique lemma (e.g. "manufacturing", "manufacturer");

(3) Replacing all the n-grams – i.e. contiguous sequences of n items from a given sequence of text – with a single term;

2.3 PHASE III: topic extraction

The LDA algorithm was used to infer the major topics addressed within the text corpus. To this end, KNIME Analytics Platform, an open-source software, was used. The algorithm requires the definition of three parameters: the Dirichlet hyperparameters (α, β) and the number of topics (T) (Blei *et al.*, 2003). Following the indications of Griffiths and Steyvers (2004), we used $\beta = 0.1$, $\alpha = 50/T$. The optimal number of topics was determined to minimize the value of perplexity, i.e. a statistical measure of how well a probability model predicts a sample (Clarkson and Robinson, 1999). A lower perplexity value suggests a better fit. As shown in Figure 2, an optimal value of 8 topics can be defined. Based on the statistical distribution of the words in the text corpus, the LDA algorithm generated the list of keywords characterizing each topic (see Table 3) and, for each document, its probability of belonging to each of the defined topics.

2.4 PHASE IV: topic labeling and validation

The LDA algorithm identifies sets of keywords associated with each topic without generating a semantic label to describe each topic (Blei, 2012). The authors of this paper used the sets of the principal 15 keywords associated with each topic to assign descriptive labels to each

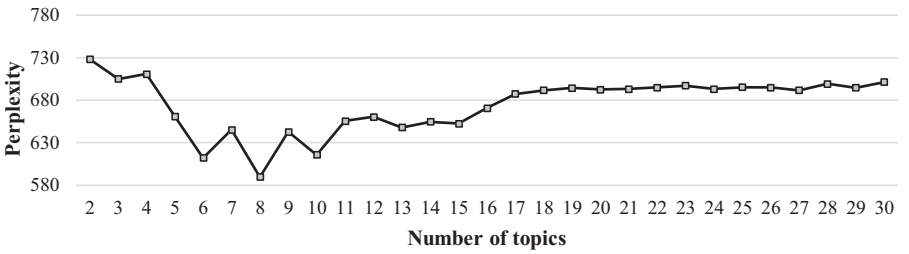

Figure 2.
Perplexity of the topic model varying the number of topics

Topic label	Description	Keywords	Sources
PSS design	Methods and tools for the design and development of Product-Service Systemsc	design, method, user, value, framework, designer, evaluation, process, development, approach, project, experience, structure, networks, customer	21%
PSS environmental and social impact	Analysis of the role played by the combined offering of product and services to effectively decrease the consumption of natural resource, to reduce the environmental impacts and to improve social equity and cohesion	sustain-, eco-, environmental, energy, consumption, business_model, technology, economic, impact, result, concept, waste, social, innovate-, potential	18%
PSS and servitization process	Analysis of the impacts and of the implications resulting from the transformation journey that involves manufacturing firms when shift to service-led strategies	servitiz-, innovation, approach, practice, implication, company, base, value, provide, study, analysis, challenge, transition, factor, interview	13%
Sustainable PSS	Methods and tools for the design and development of Product-Service Systems that consider sustainability goals	sustain-, design, environmental, method, process, approach, company, support, development, support, analysis, solution, provide, customer, tool	11%
PSS business models	Description and analysis of company's plan for how it will generate revenues and make a profit though the offering of Product-Service Systems	customer, business_model, service, value, company, product, design, business, market, framework, offer, strategy, offering, provide	10%
PSS performance analysis	Evaluation of the Product-Service Systems performance and value offering from both the customer and the p rovider perspectives	risk, evaluation, maintenance, time, cost, performance, management, uncertainty, availability, configuration, base, contract, decision, supplier, simulation	10%
PSS requirements analysis	Methods and approaches that deal with the problem of the definition of Product-Service Systems' structure and requirements	requirement, development, design, process, method, model, approach, product, support, engineering, base, develop, integrate, modeling, modeling	9%
Industrial PSS	Analysis of integrated product and service offerings in industrial applications	industrial_product_service_systems, customer, machine, manufact-, approach, process, provider, planning, quality, change, delivery, configuration, requirement, describe, integrate	8%

Table 3.
PSS topic landscape, description and top 15 keywords associated to each topic (keywords ordered by their relative importance)

topic. To test their reliability, the defined topic labels were submitted to an external panel of scholars familiar with the PSSs literature, which confirmed the identified labels. The LDA algorithm results were validated by comparing the assigned topic of a randomly selected sample composed of one hundred articles with a manual topic assignment performed by a team of four researchers on PSS-related topics. The validation showed that the LDA

algorithm produced a topic assignment that generally did not differ significantly from the results obtained by a manual categorization (estimated accuracy: 93%).

3. Topic landscape of product-service systems research

The application of the LDA algorithm resulted in the extraction of eight different topics. Table 3 reports a brief description of each topic together with the lists of keywords and the percentage of documents belonging to the topic. Some interesting considerations emerge from this table:

(1) around 21% of the scientific production on PSSs concerns "PSS design", followed by "PSS environmental and social impact" (18%) and "PSS & Servitization Process" (13%);

(2) sustainability, including both the design and environmental and social aspects, represents more than a quarter of the scientific production on PSSs (the two topics may seem overlapping, but they deal with different aspects of sustainability: the former concerns the sustainability assessment, while the latter deals with the design of sustainable PSS).

Figure 3 reports the publication trend over time of the eight identified topics. Griffiths and Steyvers (2004) proposed a distinction between hot and cold topics: while the former are topics for which the number of published articles grows over time or remains constant, the latter are topics with a decreasing number of publications. According to this view, none of the topics concerning PSSs can be defined as "cold" (see Figure 3). In particular, two topics ("PSS business models" and "PSS environmental and social impact") show a steady increase in the number of publications. Furthermore, it can be observed that some topics show a leveling in the number of publications, see for example: "Industrial PSS", "PSS requirement analysis" and "PSS & Servitization Process".

4. Product-service systems research topics

Results reported in Table 3 provide a framework to understand and analyze the vast literature corpus concerning the concept of PSSs. Since the first definition of the PSS concept, several literature reviews concerning the field of research have been published (Moro *et al.*, 2020). Most of these cover specific topics (see Table 4), whereas only a handful focused on an overall analysis of the PSS literature corpus (Tukker and Tischner, 2006; Baines *et al.*, 2007; Wang *et al.*, 2011; Beuren *et al.*, 2013). Given the highly evaluative context, most of these reviews can be considered dated, being the most recent more than seven years old (Moro *et al.*, 2020).

The following sections provide an updated overview of PSS research taking into account the theoretical framework presented in the previous sections and recent advances in PSS research.

4.1 PSS design

PSS design is the most influential topic in terms of the number of documents (21%). Studies discussing concepts, methodologies and tools aiming at supporting the design of innovative PSSs are considered part of this topic. The integration between the design process of products and services is intended as the basis for the development of novel PSS (Aurich *et al.*, 2006; Barravecchia *et al.*, 2020a, b). Due to the heterogeneous configuration of PSSs, their design is often characterized by systemic approaches useful to integrate product and service perspective (Morelli, 2006). Several studies agree that the research topic on PSS design is not

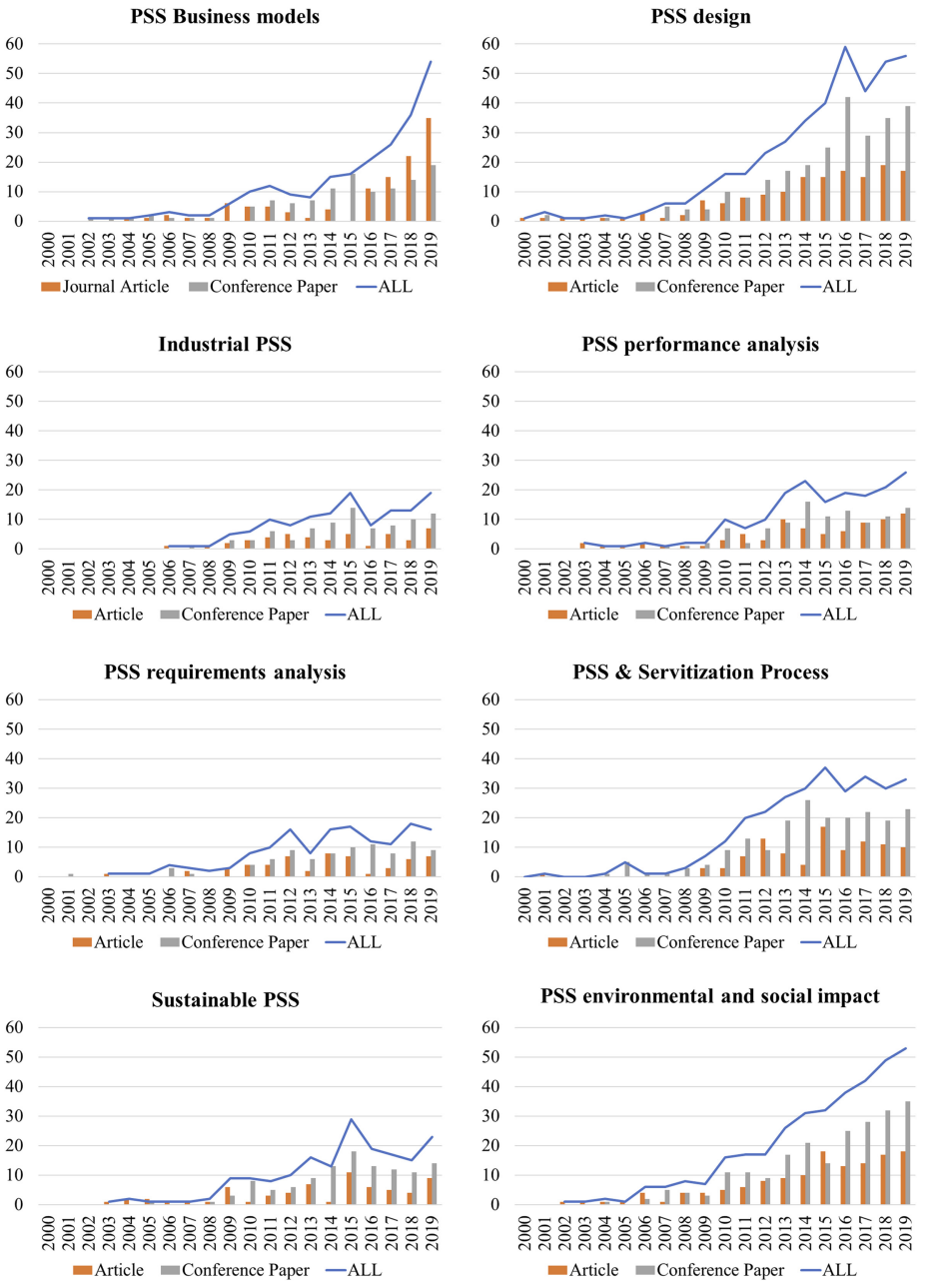

Figure 3.
Publication trend in PSS research topics

yet fully mature, a variety of dedicated methodologies have been developed; however, there are neither reference standards nor established models yet (Vasantha *et al.*, 2012).

Table 5 reports some tools specifically developed to support PSS design during the different phases of the PSS life cycle. To face this aspect, recent contributions on the topic are focusing on integrating digital technologies within PSS.

4.2 PSS environmental and social impact

The offering of PSSs may provide new opportunities in increasing sustainability (Tukker, 2004). Existing research recognizes the critical role of the combined offering of products and services to effectively decrease the consumption of natural resources, reduce environmental impacts and improve social equity and cohesion (Vezzoli *et al.*, 2015). Moreover, as Tukker (2015) argued, PSSs are one of the most effective instruments for moving society toward a circular economy.

The creation of PSSs long-term relationships with customers provides incentives to extend the useful life of the product and to optimize resource utilization (Evans *et al.*, 2007). The implementation of service-oriented strategies encourages advances in product life cycle management and facilitates the transition toward more sustainable consumption patterns (Salazar *et al.*, 2015).

Table 6 introduces and summarizes articles concerning the management and the evaluation of PSS environmental and social impact. Common elements of these studies are: the multidimensional analysis of sustainability, the comparison with traditional business models and the analysis of impacts throughout the PSS life cycle.

4.3 PSS and servitization process

The concepts of servitization and PSSs are strongly related. While the former refers to the progressive transformation process, the latter refers to the output of the servitized manufacturing companies (Beuren *et al.*, 2013).

The process of servitization has been defined as "the innovation of organization's capabilities and processes to better create mutual value through a shift from selling products to selling Product-Service Systems" (Neely, 2009). It is possible to recognize a variety of forms of servitization (Baines *et al.*, 2009; Mastrogiacomo *et al.*, 2020a), defining the so-called "product-service continuum" (Kowalkowski *et al.*, 2015), i.e. a continuum from traditional manufacturing companies to product-service providers able to manage all the PSS lifecycle and to offer complex solutions. Interaction between PSS delivery and the servitization process has been analyzed from a variety of points of view. Most characterizing works of the topic are reported in Table 7. Issues addressed are wide-ranging, covering analysis of the diffusion of the servitization process, impact on the company's performance and challenges to be faced during the transformation process.

PSS research topic	Focalized literature reviews
PSS design	Vasantha *et al.* (2012), Qu *et al.* (2016) Brambila-Macias *et al.* (2018)
PSS environmental and social impact	Tukker (2015)
PSS and servitization process	Lightfoot *et al.* (2013), Mahut *et al.* (2017)
Sustainable PSS	Lee *et al.* (2018)
PSS Business models	Reim *et al.* (2015)
PSS performance analysis	–
PSS requirements analysis	Song (2017), Berkovich *et al.* (2011), Rodríguez *et al.* (2020)
Industrial PSS	–

Table 4. Literature reviews related to specific PSS research topics

Article	Contribution
Aurich *et al.* (2006)	Life cycle oriented design method for PSS, including technical services (e.g. maintenance, retrofitting, refurbishing)
Morelli (2009)	Methodological approach to design highly customized PSS based on the active participation of customers to the value production process
Shimomura *et al.* (2009)	"Extended Service Blueprint", a method that enables the design of PSS' service components during the early phase of product design
Lim *et al.* (2012)	"PSS Board", a structured tool to visualize the PSSs development process and to support their design. The "PSS board" is a matrix where customer activities, state of the products, services, dedicated infrastructures and partners are placed in rows, and the general PSS process steps are placed in columns
Pezzotta *et al.* (2012)	"WinWin Spiral Model", a PSS engineering process that considers the iteration process and the customer involvement with a comprehensive lifecycle perspective
Carreira *et al.* (2013)	Extension of the Kansei engineering method to include the analysis of the different players that collaborate within the PSS and the study of the customer experience
Shimomura *et al.* (2015)	Method for analyzing PSS conceptual design processes. The paper provides a PSS design process visualization scheme in which the design processes are analyzed in connection with an evaluation of design solutions
Chiu *et al.* (2018)	A PSS system modeling technique for developing a systematic and complete PSS strategy. The proposed method integrates Failure Modes and Effects Analysis (FMEA) and Importance Performance Analysis (IPA) with a service-product development matrix (SPDM) to identify the needs of customers and to design new PSS solutions
Zheng *et al.* (2018)	Four-stage based design approach for service innovation of smart PSS. In detail, the four stages are: (i) platform development, (ii) data acquisition, (iii) data analytics for service innovation and (iv) digital twin-enabled service innovation
Andriankaja *et al.* (2018)	Design method based on the extension of the Functional Analysis (FA) approach to make it consistent and fully applicable for PSS design
Pezzotta *et al.* (2018)	"Product Service System Lean Design Methodology (PSSLDM)", a structured methodology to develop PSSs along their entire lifecycle
Lee *et al.* (2019)	"PRR Design Method", explicit guidelines and a systematic design approach for the design of innovative Smart PSS
Pereira *et al.* (2019)	Investigation on the distinctive pathways for PSS development

Table 5.
Tools and methodologies for PSS design

Article	Contribution
Lee *et al.* (2012)	Dynamic and multidimensional approach to measure PSS sustainability based on the combination of (i) System dynamics (SD), to covers the dynamics of PSS sustainability and (ii) Triple Bottom Line (TBL), in order to encompass the multidimensionality of PSS sustainability
Lindahl *et al.* (2014)	Quantification of environmental and economic benefits of PSS offerings in comparison with its corresponding product-sales type business
Chou *et al.* (2015)	Introduction of the concept of sustainable product-service efficiency and analysis of the relationship between product-service value and sustainability impact
Kjaer *et al.* (2016)	Investigation on the specific challenges to be addressed when using Life Cycle Assessment (LCA) to evaluate the environmental performance of PSS
Ding *et al.* (2017)	Environmental and economic sustainability-aware resource service scheduling problem (RSSP) during the product-service delivery phase of Industrial PSS
Sousa-Zomer and Miguel (2018)	Analysis of the social consequences of PSS introduction into a market. Investigation of the applicability of Social Life Cycle Assessment (SLCA) to the analysis of the social impact of PSS
Erkoyuncu *et al.* (2019)	Uncertainty-based framework to increase sustainability in industrial PSS. The study identifies the uncertainty factor in sustainable industrial service contracts

Table 6.
Tools and methodologies to manage and assess PSS sustainability

Article	Contribution
Neely (2009), Léo and Philippe (2001), Dachs *et al.* (2014), Mastrogiacomo *et al.* (2019), (2020b), (2020a)	Extent of the servitization process, PSS delivery and analysis of the typologies of services offered by manufacturing companies
Krucken and Meroni (2006), Martinez *et al.* (2010), Baines *et al.* (2013), Karlsson *et al.* (2017), Coreynen *et al.* (2017)	Opportunities, barriers and challenges encountered in the servitization journey by manufacturing companies during the servitization process
Juehling *et al.* (2010), Visnjic Kastalli and Van Looy (2013), Bustinza *et al.* (2015), Lingegård and Lindahl (2015)	Impact of PSS strategies on the performance of manufacturing companies
Lerch and Gotsch (2015)	Overview of service digitalization in industrial firms. Description of three types of digitalized PSS. Each of the three types addresses a different stage of the product life cycle and improves performance or efficiency
Wallin *et al.* (2015)	Investigation on how manufacturing companies can systematically build PSS innovation capabilities and their influence PSS innovation
Opresnik and Taisch (2015)	Investigation on how manufacturers can exploit the opportunity arising from combined Big Data and servitization
Dahmani *et al.* (2016)	Formalization of the servitization decision-making processes and definition of a reliability diagnosis procedure for servitization

Table 7.
Articles on PSS and servitization process

4.4 Sustainable PSS

LDA application resulted in the definition of a specific topic on the development of sustainable PSS, with a particular focus on increasing the environmental, social and economic sustainability of complex solutions composed of tangible elements (products) and intangible elements (services). This topic straddles two other topics identified by this analysis: "PSS design" and "PSS environmental and social impact".

PSSs developed and designed with the explicit purpose of reducing environmental impact are labeled as *sustainable PSS* (SPSS) (Roy, 2000; Vezzoli *et al.*, 2015) or *eco-efficient PSS* (EPSS) (Ceschin, 2013). Several practical methodologies have been developed over the past years to address issues related to the development of sustainable PSS. Intending to summarize the main research works, Table 8 provides an overview of articles on the subject.

4.5 PSS business models

PSSs can be seen as new opportunities to create new business models. A growing number of manufacturing companies are shifting their focus to services as a new way of creating and capturing added value (Adrodegari *et al.*, 2017b). The emerging of complex offerings composed of products and services implies a transition from revenue streams mainly determined by selling products to revenue mechanisms based on customer relationship and service provisions (Mathieu, 2001).

Several studies noted that business models are critical for the success of PSS implementations (Kindström, 2010). This is confirmed by the results reported in section 3, according to which a significant number of papers on PSS deal directly with business model issues, and the topic is also closely related to many other research topics.

There is a general consensus on categorizing the PSS business model into three types: product-oriented, use-oriented and result-oriented business models (Tukker, 2004). These three types of business models can be applied in both consumer-oriented and B2B contexts

Article	Contribution
Manzini and Vezzoli (2003)	General working framework to describe the sustainable or eco-efficient potentials of PSS and implications for the design discipline
Maxwell *et al.* (2006)	"Sustainable Product and Service Development (SPSD) approach", a practical method for the development of sustainable PSS which incorporates existing corporate strategy related to cleaner production and product development systems
Geum and Park (2011)	A systematic application of the service blueprint in PSS design to elucidate the relationship between products and services and to understand how PSS can provide sustainable production and consumption
Vezzoli *et al.* (2015)	Challenges in the implementation of "Sustainable Product-Service Systems"
Joore and Brezet (2015)	"Multilevel Design Model (MDM)", practical approach that combines the design of physical artefacts, the design of product-service systems and the identification of complex social change which may occur
Chierici and Copani (2018)	Structured definition and configuration of innovative remanufacturing-with-upgrade business models as a mean for developing sustainable PSS
Song and Sakao (2017)	Framework for the customization of sustainable PSS in early design phases

Table 8.
Tools and methodologies to develop sustainable PSS

(e.g. industrial PSS). Besides this, several business model classifications of PSS have been defined (Barquet *et al.*, 2013; Adrodegari *et al.*, 2017a).

Most of the studies related to PSS business models are highly related to a particular application or to the implementation of sustainable strategies integrating both the economic and the environmental aspects (Boons *et al.*, 2013; Yang *et al.*, 2017). Table 9 shows the most characterizing papers on this topic.

4.6 PSS performance analysis

The performance analysis of PSS is a fundamental step in the implementation of innovative service-oriented strategies (Qu *et al.*, 2016). There is a broad agreement among experts about the critical role played by the in-depth evaluation of PSSs performance in their management and productivity (Baines *et al.*, 2007).

Additional challenges for the performance analysis are posed by the PSS heterogeneity being composed of tangible products, intangible services, infrastructures. Traditional tools

Article	Contribution
Barquet *et al.* (2013)	Link between competitiveness and PSS implementation strategies
Parida *et al.* (2014)	Taxonomy of PSS business models composed of four categories; (i) add-on customer services; (ii) maintenance and product support services; (iii) R&D-oriented services and (iv) functional and operational services
Yang *et al.* (2017)	Framework of using value uncaptured for sustainable business model innovation
Adrodegari *et al.* (2017a, b)	Two-level hierarchical BM framework that can be used to describe PSS business models and guide their development by capital goods companies
Sholihah *et al.* (2019)	PSS business alignment that enables the manufacturer to identify the strategic objective of its service transition strategy and align it with PSS business model
Yang and Evans (2019)	Relationship between PSS business models and sustainability performance
Evans *et al.* (2007)	Case study: Product-oriented PSS for food delivery services
Azarenko *et al.* (2009)	Case study: Result-oriented PSS for machine tool industry
Ng *et al.* (2009)	Case study: Result-oriented PSS for defense industry
Kuo (2011)	Case study: Use-oriented PSS for office copy machine
Besch (2005)	Case study: Use-oriented PSS for office furniture

Table 9.
Articles on PSS business models

developed for the analysis of products and services are not capable of capturing the complexity of PSS (Rondini *et al.*, 2020). To face this issue, several authors proposed practical approaches and methodologies for evaluating the performance of a PSS. Some of these are adaptations of pre-existing approaches (Geng and Chu, 2012), while others have been explicitly developed for PSS (Rondini *et al.*, 2020). Table 10 shows the most influential papers on this topic.

4.7 PSS requirements analysis

Given the complexity of value offerings composed of a mix of tangible and intangible elements, the requirement analysis carved out a niche in the scientific literature on PSS. The definition of PSS structure and requirements is a necessary preliminary stage for their design (Wiesner *et al.*, 2017). The definition of the requirements of a PSS cannot disregard some essential elements: the consideration of the entire PSS life cycle, the demand for customized solutions, the involvement of different stakeholders in the value creation process and the additional services associated with the primary offering (Berkovich *et al.*, 2011). Several attempts have been made to define novel methods or to adapt existing approaches to the problem of defining PSS requirements (Cavalieri and Pezzotta, 2012). Table 11 shows the state-of-the-art on this topic.

Article	Contribution
Sakao and Lindahl (2012)	Method for evaluating and selecting PSS Offerings (PSSOs). The method is divided into four steps (collecting information; determining objective function; deriving optimized PSSOs; feedback to idea creation) and is focused on the customer viewpoint
Geng and Chu (2012)	Revision of the Importance-Performance Analysis (IPA) to identify PSS improvement strategies in order to evaluate customer satisfaction
Kim *et al.* (2013)	Set of evaluation criteria designed to consider provider and customer perspectives and all the 3P (profitability, planet and people) dimensions
Pan and Nguyen (2015)	Combination of the Balanced Scorecard (BSC) and Multiple Criteria Decision Making (MCDM) to identify the key performance evaluation criteria for achieving customer satisfaction in PSS delivery
Rondini *et al.* (2017)	Adoption of Business Process Simulation (BPS) approach to support the assessment of the service provision process in PSS strategies
Mourtzis *et al.* (2018)	Methodology to support companies in the identification of the degree of customization of their PSS
Ziaee Bigdeli *et al.* (2018)	Framework to assess the transformation journey and to evaluate the outcomes of a manufacturer becoming a provider of advanced services
Matschewsky *et al.* (2020)	"Provider Value Analysis (PVA)", empirically-based approach to facilitate a structured assessment of the value capture during the provision of PSSs
Rondini *et al.* (2020)	"Engineering Value Assessment (EVA)", two-step procedure composed of multi-criteria decision-making methods for a comprehensive value assessment of PSS, considering the perspectives of both customers and providers
Barravecchia *et al.* (2020a, b), Mastrogiacomo *et al.* (2021)	Methodology for leveraging and analyzing user-generated content for PSS quality measurement and management

Table 10.
Articles on PSS performance analysis

Article	Contribution
Morelli (2006)	Methods to define a map of the actors involved in PSS, the PSS requirements, the PSS structure and to represent and blueprint a PSS
Maussang *et al.* (2009)	Tool that considers the interactions between physical objects and service units to recognize the whole system's requirements
Geng *et al.* (2010)	QFD application to measure the importance of PSS specifications to satisfy the customer requirements
Geng and Chu (2012)	Method to support the definition of PSS requirements both concerning the customer and the manufacturer
Song *et al.* (2013)	Definition of requirements in the early development phase of Industrial Product-Service System
Berkovich *et al.* (2014)	"Requirement Data Model (RDMod)", a model that describes different types of requirements and the relations between them
Shimomura *et al.* (2018)	Methodology that employs a scenario approach for the definition of PSS requirements. Investigation on the difficulty in analyzing what should be offered to create value in the social system
Wiesner *et al.* (2017)	Investigation on requirement engineering for PSS including Cyber-Physical Systems
Fargnoli and Haber (2019)	Methodology based on the analysis of the market demand and customer requirements by means of the Quality Function Deployment for Product Service System (QFDforPSS) and the Analytic Network Process (ANP) methods

Table 11.
Articles on PSS requirement analysis

4.8 Industrial PSS

According to Meier *et al.* (2010), "an industrial product-service system (IPSS) is characterized by the integrated and mutually determined planning, development, provision and use of product and service shares including its immanent software components in business-to-business applications and represents a knowledge-intensive socio-technical system".

A shift from product and technology-centered strategies toward the offering of complex solutions comprising both product and services is taking place also in contexts characterized by business-to-business relationships (Meier *et al.*, 2011).

This topic has been analyzed from different perspectives (see Table 12). Apart from a few articles that have defined the concept of Industrial PSS, most of the articles are contaminated by other research topics, in particular by the requirements analysis, design and performance evaluation.

Article	Contribution
Roy and Cheruvu (2009), Meier *et al.* (2010), (2011)	Definition of the concept of IPSS and the motivation of the transformation
Schweitzer and Aurich (2010)	Analysis of the Continuous Improvement Process (CIP) in IPSS delivery
Erkoyuncu *et al.* (2011)	Taxonomy of the sources of uncertainty for service cost estimation of IPSS
Datta and Roy (2011)	Conceptual framework for operations strategy in performance-based IPSS
Durugbo (2014)	Methodology to manage the co-design process within the context of IPSS
Pezzotta *et al.* (2016)	Application of the SErvice Engineering Methodology (SEEM) for the development of IPSS
Zhu *et al.* (2011), Azarenko *et al.* (2009)	IPSS application - Machine and cutting tools
Pezzotta *et al.* (2016)	IPSS application - Power and automation solutions
Durugbo (2014)	IPSS application - Microsystems

Table 12.
Articles on industrial PSS

4.9 Relationship between topics

The results of the LDA algorithm allow the construction of a topic network graph, i.e. a directed graph in which nodes represent topics and directed arcs indicate relationships between topics. In detail, the graph shows an arc between two topics, say from "Topic A" to "Topic B", when documents belonging to "Topic A" have an average probability of belonging to "Topic B" above a certain threshold. For the purpose of this analysis, the selected threshold was set to 5%. The resulting graph is shown in Figure 4.

"PSS business models" and "PSS design" nodes show the most incoming arcs. This evidence suggests that these two topics are cross-cutting and intertwined with most of the others. The literature review confirms this evidence. The concept of business model and the process of developing and designing novel PSS are also addressed in many of the pivotal papers in other topics. For example, the provision of industrial PSS cannot be achieved without the definition of new business models for the specific industry context or the application of PSS design approaches.

Newer, less developed topics such as "Industrial PSS" have no incoming arcs, meaning it has limited relevance within the documents belonging to any other topics.

5. Future trends in product-service systems research

While previous sections provided structure and interpretation to PSS research, looking at past and present scientific production as well as the relationships between topics, the purpose of this section is to outline potential research trends and challenges yet to be tackled.

5.1 Smart PSS and digital servitization

In parallel with the spread of the concept of PSS and service-oriented business models, there has been a growing diffusion of digital technologies. In recent years, these two once distinct

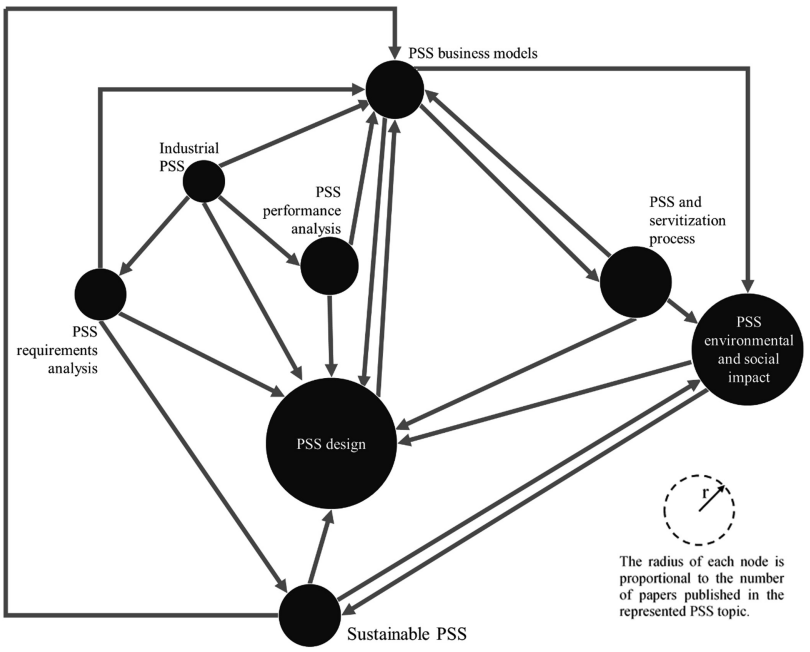

Figure 4.
Topic network graph of product-service systems research

fields of research converged (Zheng *et al.*, 2019). Digitalization supports companies in the development of new services, business models and innovative products. This process is generally defined as digital servitization (Kohtamäki *et al.*, 2019). The outputs of the companies that faced the process of digital servitization are PSS that exploit digital technologies, commonly labeled as Smart-PSS, digital PSS, cyber-physical PSS, IoT-enabled PSS, digital-driven PSS (Zheng *et al.*, 2019).

The LDA algorithm (see section 2) did not recognize a specific topic related to these issues, but assigned the articles dealing with these issues to the eight PSS research topics. This result tells us that technology and Smart PSS does not yet represent a pillar of PSS research. Despite this, given the growing importance of digital servitization in research and practice, this area will represent a major challenge for PSS research in all the eight identified topics.

In recent years, interest in smart PSS has grown exponentially (see Figure 5). According to data reported in Figure 5, it can be inferred that Smart PSS is rapidly becoming "hot topic" in the coming years. This fact is also supported by the results of the LDA algorithm. From 2014, most topics have seen the emergence of prominent articles addressing issues related to the deployment of Smart PSS (see Table 13).

The analysis of the literature and debate with researchers and practitioners revealed several possible RQs still to be addressed. These potential RQs are reported in Table 14 by dividing them into the eight PSS research topics and the key phases of the PSS life cycle.

Current literature on traditional PSS guided the definition of these RQs. Problems already faced in the study of traditional PSS require new considerations to successfully address the new challenges posed by the implementation of Smart PSS. For instance, consider RQ 1.4, 1.6 and 1.10. These issues were considered critical ten years ago for the development of traditional PSS. The same issues became critical again with the emergence of Smart PSS. Similar considerations can be made for the other phases of the PSS life cycle. See for example

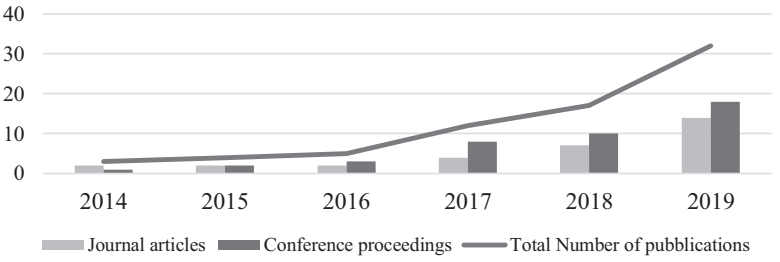

Figure 5.
Trend of publications on PSS and digital-related topics

Research topic	Articles
PSS design	Valencia *et al.* (2015), Zheng *et al.* (2018), Lee *et al.* (2019)
PSS environmental and social impact	Bressanelli *et al.* (2018)
PSS and servitization process	Lerch and Gotsch (2015)
Sustainable PSS	–
PSS Business models	Zancul *et al.* (2016), Takenaka *et al.* (2016), Bo *et al.* (2019)
PSS performance analysis	Lu *et al.* (2019), Liu *et al.* (2019b)
PSS requirements analysis	Wang *et al.* (2019)
Industrial PSS	Liu *et al.* (2019a)

Table 13.
Articles concerning Smart PSS in the eight PSS research topics

Table 14. Potential research questions (RQs) and challenges for Smart PSS research

		PSS LIFECYCLE PHASES		
		(1) PSS development	(2) PSS delivery	(3) PSS end-of-life
PSS RESEARCH TOPICS	PSS design	(1) (RQ 1.1) 1How can digital technologies be included in existing PSS? (2) (RQ 1.2) How digital technologies impact on the PSS design?	(1) (RQ 2.1) Thanks to digital technologies, is it possible to design customized PSS in real-time (self-adaptable solutions)? (2) (RQ 2.2) How to improve PSS customer experience applying digital technologies?	(1) (RQ 3.1) How can the end of life of PSS be considered at an early stage of design? Furthermore, how can digital technologies contribute to this?
	PSS environmental and social impact	(1) (RQ 1.3) Which digital tools can be implemented during the development of a PSS to improve its future sustainability performance?	(1) (RQ 2.3) How extend the usage phase of PSS lifecycle applying digital technologies? (2) (RQ 2.4) What are the effects on the social sustainability of Smart PSS?	(1) (RQ 3.2) How can digital technologies reduce the environmental impact of the end of life of a PSS?
	PSS and servitization process	(1) (RQ 1.4) What is the extent of digital servitization? What are the challenges that manufacturing companies face and the main barriers? (2) What core competencies and capabilities are required to approach the digital servitization process?	(1) (RQ 2.5) How can servitized companies leverage user-generated data from smart PSS to increase their competitiveness?	(1) (RQ 3.3) How can servitized companies benefit from smart recycling strategies?
	Sustainable PSS	(1) (RQ 1.5) How to integrate digital technologies in the early stages of development of PSS to reduce their environmental impact?	(1) (RQ 2.6) How can the user-generated data collected by connected PSS improve their sustainability performance? (2) (RQ 2.7) What impact can smart maintenance operations have on the sustainability of a PSS? Furthermore, how to implement these maintenance strategies?	(1) (RQ 3.4) How can digital technologies facilitate the process of reuse and conversion of PSS at the end of their life cycle? (2) (RQ 3.5) How to integrate IoT technologies to facilitate the recycling of tangible components of a PSS?
	PSS Business models	(1) (RQ 1.6) Can the introduction of digital technologies lead to new business models for PSS? (2) (RQ 1.7) How to integrate digital platforms in PSS business models? (3) (RQ 1.8) How to facilitate circular economy practices using Smart PSS?	(1) (RQ 2.8) How can value-cocreation be improved in Smart PSS? (2) (RQ 2.9) What are the opportunities offered by collaborative consumption strategies during the usage phases of PSS?	(1) (RQ 3.6) Is it possible to define new business models based on the residual end-of-life value of PSS? Moreover, how digital technologies can drive these business models?
	PSS performance analysis	(1) (RQ 1.9) How does the addition of digital technology development impact the performance of a PSS design?	(1) (RQ 2.10) How to optimally use IoT technologies to monitor PSS performance? (2) (RQ 2.11) How to measure perceived quality and customer satisfaction of smart PSS?	(1) (RQ 3.7) How to measure the performance of smart recycling activities?
	PSS requirements analysis	(1) (RQ 1.10) Which new requirement categories should be considered for the development of Smart PSS?	(1) (RQ 2.12) How can smart PSS collect new requirement during their delivery? (2) (RQ 2.13) How can big data analysis influence requirement elicitation?	(1) (RQ 3.8) What new requirements must be considered for the development of PSS, including smart recycling strategies?
	Industrial PSS	(1) (RQ 1.11) How can Cyber-Physical industrial systems be adapted to incorporate PSS logic?	(1) How can smart industrial PSS improve relationships between players in manufacturing ecosystems?	(1) Is the reuse or conversion of the tangible component of a smart industrial PSS feasible? How can digital technologies contribute?

RQ 2.4, 2.5, 2.11 for the Delivery phase and RQ 3.2, 3.4, 3.8 for the end-of-life phase of the PSS lifecycle.

Taken together, these challenges provide us with an overview of what is needed for full implementation of smart PSS and what are the main open issues requiring further investigation.

5.2 PSS and emerging technological issues

The previous section highlighted the challenges that need to be addressed to link PSS research with currently diffused digital technologies. However, researchers and companies must also prepare to face new challenges arising from the emergence of new technological paradigms that will invest the digital world and beyond. In this respect, an analysis of the relationships between the top technological trends and PSS research topics deserves more attention. Every year Gartner, a world's leading research and advisory company, highlights strategic trends, including the most promising emerging technologies and business innovations (Panetta, 2019).

Table 15 relates each technological trend with the identified eight PSS research topics and reports the number of articles published in each area. Data were retrieved from Scopus database (Scopus Elsevier, 2020). This table reveals that research on PSS related to emerging technological trends is still limited and particularly recent.

In detail, few studies investigated the relationship between hyperautomation and PSS, mainly focusing on the application of data mining algorithms for the evaluation and management of PSS (Wiesner *et al.*, 2017; Shimomura *et al.*, 2018). Issues related to multiexperience were partially covered by analyzing the use of augmented reality equipment and smart devices for the maintenance and monitoring of industrial plants with a Product-Service approach (Mourtzis *et al.*, 2017).

Transparency and traceability, empowered edge, distributed cloud and autonomous things received more, albeit limited, attention in various PSS research topics.

Recent studies associated the study of empowered edge to the topic of industrial PSS (Liu *et al.*, 2019a) and to the design of IoT-based PSSs (Shao *et al.*, 2019). Few works have explored opportunities resulting from edge-computing and the implementation of IoT technologies in the servitization process (Heinis *et al.*, 2018).

Issues related to transparency and traceability were mainly addressed in the study of sustainable consumption and production practices of PSS (Pialot *et al.*, 2017; Sakao, 2019). The impact of distributed cloud on PSS strategies is an area partially covered. So far, the study of the distributed cloud paradigm related to the PSS concept resulted in the definition of smart PSSs design tools (Zheng *et al.*, 2018). Finally, concerning autonomous things, some studies have analyzed their design in specific PSS application, such as autonomous vehicles (Wang *et al.*, 2018) or collaborative robots (Cordeiro, 2018).

Many technological trends (democratization, human augmentation, practical blockchain and AI security) resulted in having no connection with current PSS research.

Table 15 shows several uncovered areas and emphasizes potential issues that would be matter of research in the PSS field. If the debate on PSS is to be moved forward, a better understanding of the influence of emerging technologies on PSS research topics needs to be developed.

In the past twenty years, the PSS concept advanced in different contexts: product, service and software sector. Nowadays, as aforementioned, the concept of PSS and that of digital transformation are inevitably approaching each other. Business models based on the delivery of tangible products and intangible services contaminate a wide range of sectors and new emerging trends will not be unaffected. It is therefore crucial starting to understand how to leverage these technologies to develop more effective, innovative and sustainable PSS.

Top 10 strategic technology trends (Panetta, 2019)	Description	Total number of articles	PSS design	PSS environmental and social impact	PSS and servitization process	Sustainable PSS	PSS business models	PSS performance analysis	PSS requirements analysis	Industrial PSS
Hyperautomation	Application of advanced technologies and AI to automate processes that normally require human resources	6 (5)*	0	0	1	0	0	1	2	2
Multiexperience	Evolution from the traditional idea of customer experience, traditionally based on a single point of contact	3 (3)*	0	0	0	0	0	0	0	3
Democratization	Process that aims to provide people with easy access to technical or business competencies	0	0	0	0	0	0	0	0	0
Human augmentation	Use of technologies to enhance human productivity and improve or restore human capabilities	0	0	0	0	0	0	0	0	0
Transparency and traceability	Process that is inducing an increasing number of customers to request more responsible and transparent personal data processing policies	17 (7)*	2	6	2	1	2	1	1	2

(*continued*)

Table 15. Relationship between the top 10 Strategic Technology Trends in 2020 (Panetta, 2019) and PSS research topics. The symbol (*) highlights articles published from 2017 to 2019

Table 15.

Top 10 strategic technology trends (Panetta, 2019)	Description	Total number of articles	PSS design	PSS environmental and social impact	PSS and servitization process	Sustainable PSS	PSS business models	PSS performance analysis	PSS requirements analysis	Industrial PSS
The empowered edge	New technology paradigm where information processing, content collection and delivery are located closer to the sources of the information	27 (21)*	6	1	6	2	7	3	1	1
The distributed cloud	New cloud paradigm based on the storage of data outside the provider's data centres	14 (11)*	5	0	3	0	1	2	0	3
Autonomous things	Diffusion of autonomous objects, including vehicles, industrial robots, drones, ships	10 (8)*	1	0	2	0	2	3	1	2
Practical blockchain	Open, distributed ledger that can record transactions between two parties efficiently and in a verifiable and permanent way	0	0	0	0	0	0	0	0	0
AI security	Tools and techniques that leverage artificial intelligence (AI) to autonomously identify and/or respond to cyber threats	0	0	0	0	0	0	0	0	0

In addition to core topics presented in previous sections, further research could usefully attempt to shed light on how these new technologies could impact on the design, management and provision of PSS.

6. Discussion and conclusions

The analysis reported in this article provides insight into what PSS research has been over the past 20 years and offers a key to understanding how it might evolve in the near future.

Given the vastness of the body of literature on PSSs, machine learning and text mining techniques were applied to understand its structure.

Eight topics were identified as pillars of research related to PSSs: (1) PSS design; (2) PSS environmental and social impact; (3) PSS and servitization process; (4) sustainable PSS; (5) PSS business models; (6) PSS performance analysis; (7) PSS requirements analysis and (viii) industrial PSS. "PSS design" and "PSS environmental and social impact" are the two most discussed topics in terms of the number of articles published.

This research confirms the vital link between research on PSS and research on the development of environmentally and socially sustainable production systems. It also reinforces the notion that the advent of the PSS paradigm has necessitated the development of new business models capable of capturing the value generated by the joint offering of products and services. The topic related to PSS business models was found to be central to the literature on PSS and closely related to the other research topics.

Twenty years of research may seem like a long time, but it is very short compared to other fields of research. Therefore, we should expect continued research on the topics identified, delving into particular aspects and providing operational tools to implement, evaluate and improve PSS over time. Alongside the eight identified research topics, however, we can expect others to emerge. Section 5 attempted to identify some of them. The PSS technological aspect is likely to play a key role in the development of the field. Digitization and emerging technologies will contaminate the PSS concept and make it relevant for coming years.

The result of this study strengthens the idea that PSSs often pose significant challenges to a broad range of discipline, ranging from engineering to design and management. For this reason, a map for navigating the literature on PSS can be useful for a variety of subjects. Researchers and practitioners approaching this field can understand how PSS research is structured and can identify key topics and articles, open issues and research gaps that need to be addressed. Conversely, for researchers who are already addressing PSS-related issues, the results of this study may be useful in positioning their research within a framework that may allow them to identify new research opportunities. Finally, research funding organizations and institutions could use the proposed topic landscape to focus and target support and funding.

Further research will be addressed to deepen the analysis between strategic technology trends and PSS research topics.

References

Adrodegari, F., Saccani, N., Kowalkowski, C. and Vilo, J. (2017a), "PSS business model conceptualization and application", *Production Planning and Control*, Vol. 28 No. 15, pp. 1251-1263.

Adrodegari, F., Pashou, T. and Saccani, N. (2017b), "Business model innovation: process and tools for service transformation of industrial firms", *Procedia CIRP*, Vol. 64, pp. 103-108.

Andriankaja, H., Boucher, X. and Medini, K. (2018), "A method to design integrated product-service systems based on the extended functional analysis approach", *CIRP Journal of Manufacturing Science and Technology*, Vol. 21, pp. 120-139.

Annarelli, A., Battistella, C. and Nonino, F. (2016), "Product service system: a conceptual framework from a systematic review", *Journal of Cleaner Production*, Vol. 139, pp. 1011-1032.

Antons, D. and Breidbach, C.F. (2018), "Big data, big insights? Advancing service innovation and design with machine learning", *Journal of Service Research*, Vol. 21 No. 1, pp. 17-39.

Asmussen, C.B. and Møller, C. (2019), "Smart literature review: a practical topic modelling approach to exploratory literature review", *Journal of Big Data*, Vol. 6 No. 1, p. 93.

Aurich, J.C., Fuchs, C. and Wagenknecht, C. (2006), "Life cycle oriented design of technical Product-Service Systems", *Journal of Cleaner Production*, Vol. 14 No. 17, pp. 1480-1494.

Azarenko, A., Roy, R., Shehab, E. and Tiwari, A. (2009), "Technical product-service systems: some implications for the machine tool industry", *Journal of Manufacturing Technology Management*, Vol. 20 No. 5, pp. 700-722.

Baines, T.S., Lightfoot, H.W., Evans, S., Neely, A., Greenough, R., Peppard, J., Roy, R., Shehab, E., Braganza, A., Tiwari, A., Alcock, J.R., Angus, J.P., Basti, M., Cousens, A., Irving, P., Johnson, M., Kingston, J., Lockett, H., Martinez, V., Michele, P., Tranfield, D., Walton, I.M. and Wilson, H. (2007), "State-of-the-art in product-service systems", *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, Vol. 221 No. 10, pp. 1543-1552.

Baines, T.S., Lightfoot, H.W., Benedettini, O. and Kay, J.M. (2009), "The servitization of manufacturing: a review of literature and reflection on future challenges", *Journal of Manufacturing Technology Management*, Vol. 20 No. 5, pp. 547-567.

Baines, T., Lightfoot, H., Smart, P. and Fletcher, S. (2013), "Servitization of manufacture: exploring the deployment and skills of people critical to the delivery of advanced services", *Journal of Manufacturing Technology Management*, Vol. 24 No. 4, pp. 637-646.

Barquet, A.P.B., de Oliveira, M.G., Amigo, C.R., Cunha, V.P. and Rozenfeld, H. (2013), "Employing the business model concept to support the adoption of product-service systems (PSS)", *Industrial Marketing Management*, Vol. 42 No. 5, pp. 693-704.

Barravecchia, F., Mastrogiacomo, L. and Franceschini, F. (2020a), "Categorizing quality determinants mining user-generated contents", *Sustainability*, Vol. 12 No. 23, p. 9944.

Barravecchia, Mastrogiacomo, L. and Franceschini, F. (2020b), "The Player-Interface method: an approach to support Product-Service Systems concept generation and prioritization", *Journal of Engineering Design*, Vol. 31 No. 5, pp. 331-348.

Berkovich, M., Leimeister, J.M. and Krcmar, H. (2011), "Requirements engineering for product service systems: a state of the art analysis", *Business and Information Systems Engineering*, Vol. 3 No. 6, pp. 369-380.

Berkovich, M., Leimeister, J.M., Hoffmann, A. and Krcmar, H. (2014), "A requirements data model for product service systems", *Requirements Engineering*, Vol. 19 No. 2, pp. 161-186.

Besch, K. (2005), "Product-service systems for office furniture: barriers and opportunities on the European market", *Journal of Cleaner Production*, Vol. 13 Nos 10–11, pp. 1083-1094.

Beuren, F.H., Gomes Ferreira, M.G. and Cauchick Miguel, P.A. (2013), "Product-service systems: a literature review on integrated products and services", *Journal of Cleaner Production*, Vol. 47, pp. 222-231.

Blei, D.M. (2012), "Probabilistic topic models", *Communications of the ACM*, Vol. 55 No 4, pp. 77-84.

Blei, D.M., Ng, A.Y. and Jordan, M.I. (2003), "Latent Dirichlet allocation", *Journal of machine Learning research*, Vol. 3, pp. 993-1022.

Bo, Z., Xiaohua, S. and Binhui, Z. (2019), "SDIV: Service-Defined Intelligent Vehicle towards the 2020 urban mobility", *Advanced Engineering Informatics*, Vol. 39, pp. 203-213.

Boons, F., Montalvo, C., Quist, J. and Wagner, M. (2013), "Sustainable innovation, business models and economic performance: an overview", *Journal of Cleaner Production*, Vol. 45, pp. 1-8.

Brambila-Macias, S.A., Sakao, T. and Kowalkowski, C. (2018), "Bridging the gap between engineering design and marketing: insights for research and practice in product/service system design", *Design Science*, Vol. 4, pp. 1-61.

Bressanelli, G., Adrodegari, F., Perona, M. and Saccani, N. (2018), "Exploring how usage-focused business models enable circular economy through digital technologies", *Sustainability (Switzerland)*, Vol. 10 No. 3, pp. 1-21.

Bustinza, O.F., Bigdeli, A.Z., Baines, T. and Elliot, C. (2015), "Servitization and competitive advantage : the importance of organizational structure and value chain position", *Research Technology Management*, Vol. 58 No. 5, pp. 53-60.

Carreira, R., Patrício, L., Jorge, R.N. and Magee, C.L. (2013), "Development of an extended Kansei engineering method to incorporate experience requirements in product-service system design", *Journal of Engineering Design*, Vol. 24 No. 10, pp. 738-764.

Cavalieri, S. and Pezzotta, G. (2012), "Product-service systems engineering: State of the art and research challenges", *Computers in Industry*, Vol. 63 No. 4, pp. 278-288.

Ceschin, F. (2013), "Critical factors for implementing and diffusing sustainable product-service systems: insights from innovation studies and companies' experiences", *Journal of Cleaner Production*, Vol. 45, pp. 74-88.

Chierici, E. and Copani, G. (2018), "Remanufacturing with upgrade PSS for new sustainable business models", *CIRP Journal of Manufacturing Science and Technology*, Vol. 29, Part B, pp. 245-256.

Chiu, M.-C., Chu, C.-Y. and Chen, C.-C. (2018), "An integrated product service system modelling methodology with a case study of clothing industry", *International Journal of Production Research*, Vol. 56 No. 6, pp. 2388-2409.

Chou, C.-J., Chen, C.-W. and Conley, C. (2015), "An approach to assessing sustainable product-service systems", *Journal of Cleaner Production*, Vol. 86, pp. 277-284.

Clarkson, P. and Robinson, T. (1999), 'Towards improved language model evaluation measures', *in Sixth European Conference on Speech Communication and Technology*.

Cordeiro, C.M. (2018), "Manifestation of intent in product-service systems. A study of type of sensing in collaborative robots", *Revue Europeenne d' Economie et Management des Services*, Vol. 1 No. 5, pp. 97-131.

Coreynen, W., Matthyssens, P., De Rijck, R. and Dewit, I. (2017), "Internal levers for servitization: how product-oriented manufacturers can upscale product-service systems", *International Journal of Production Research*, Vol. 56 No. 6, pp. 2184-2198.

Dachs, B., Biege, S., Borowiecki, M., Lay, G., Jäger, A. and Schartinger, D. (2014), "Servitisation of European manufacturing: evidence from a large scale database", *The Service Industries Journal*, Vol. 34 No. 1, pp. 5-23.

Dahmani, S., Boucher, X., Peillon, S. and Besombes, B. (2016), "A reliability diagnosis to support servitization decision-making process", *Journal of Manufacturing Technology Management*, Vol. 27 No. 4, pp. 502-534.

Datta, P.P. and Roy, R. (2011), "Operations strategy for the effective delivery of integrated industrial product-service offerings: two exploratory defence industry case studies", *International Journal of Operations and Production Management*, Vol. 31 No. 5, pp. 579-603.

Ding, K., Jiang, P. and Zheng, M. (2017), "Environmental and economic sustainability-aware resource service scheduling for industrial product service systems", *Journal of Intelligent Manufacturing*, Vol. 28 No. 6, pp. 1303-1316.

Durugbo, C. (2014), "Strategic framework for industrial product-service co-design: findings from the microsystems industry", *International Journal of Production Research*, Vol. 52 No. 10, pp. 2881-2900.

Erkoyuncu, J.A., Roy, R., Shehab, E. and Cheruvu, K. (2011), "Understanding service uncertainties in industrial product-service system cost estimation", *International Journal of Advanced Manufacturing Technology*, Vol. 52 Nos 9–12, pp. 1223-1238.

Erkoyuncu, J.A., Roy, R., Shehab, E., Durugbo, C., Khan, S. and Datta, P. (2019), "An effective uncertainty based framework for sustainable industrial product-service system transformation", *Journal of Cleaner Production*, Vol. 208, pp. 160-177.

Evans, S., Partidário, P.J. and Lambert, J. (2007), "Industrialization as a key element of sustainable product-service solutions", *International Journal of Production Research*, Vol. 45 Nos 18–19, pp. 4225-4246.

Fang, D., Yang, H., Gao, B. and Li, X. (2018), "Discovering research topics from library electronic references using latent Dirichlet allocation", *Library Hi Tech*, Vol. 36 No. 3, pp. 400-410.

Fargnoli, M. and Haber, N. (2019), "A practical ANP-QFD methodology for dealing with requirements' inner dependency in PSS development", *Computers and Industrial Engineering*, Vol. 127, pp. 536-548.

Geng, X. and Chu, X. (2012), "A new importance-performance analysis approach for customer satisfaction evaluation supporting PSS design", *Expert Systems with Applications*, Vol. 39 No. 1, pp. 1492-1502.

Geng, X., Chu, X., Xue, D. and Zhang, Z. (2010), "An integrated approach for rating engineering characteristics' final importance in product-service system development", *Computers and Industrial Engineering*, Vol. 59 No. 4, pp. 585-594.

Geum, Y. and Park, Y. (2011), "Designing the sustainable product-service integration: a product-service blueprint approach", *Journal of Cleaner Production*, Vol. 19 No. 14, pp. 1601-1614.

Goedkoop, M.J., van Halen, C.J.G., te Riele, H.R.M. and Rommens, P.J.M. (1999), *Product Service Systems, Ecological and Economic Basics*, Report for Dutch Ministries of Environment and Economic Affairs.

Griffiths, T.L. and Steyvers, M. (2004), "Finding scientific topics", *Proceedings of the National Academy of Sciences*, Vol. 101 suppl 1, pp. 5228-5235.

Hansch Beuren, F. and Cauchick Miguel, P.A. (2013), "First steps to construct a life cycle framework for PSS", in *22nd International Conference on Production Research, ICPR 2013*.

Harzing, A.-W. and Alakangas, S. (2016), "Google scholar, Scopus and the web of science: a longitudinal and cross-disciplinary comparison", *Scientometrics*, Vol. 106 No. 2, pp. 787-804.

Heinis, T.B., Loy, C.L. and Meboldt, M. (2018), "Improving usage metrics for pay-per-use pricing with IoT technology and machine learning: IoT technology and machine learning can identify and capture advanced metrics that make pay-per-use servitization models viable for a wider range of applications", *Research Technology Management*, Vol. 61 No. 5, pp. 32-40.

Joore, P. and Brezet, H. (2015), "A multilevel design model: the mutual relationship between product-service system development and societal change processes", *Journal of Cleaner Production*, Vol. 97, pp. 92-105.

Juehling, E., Torney, M., Herrmann, C. and Droeder, K. (2010), "Integration of automotive service and technology strategies", *CIRP Journal of Manufacturing Science and Technology*, Vol. 3 No. 2, pp. 98-106.

Karlsson, A., Larsson, L. and Öhrwall Rönnbäck, A. (2017), "Product-service system innovation capabilities: linkages between the fuzzy front end and subsequent development phases", *International Journal of Production Research*, Vol. 56 No. 6, pp. 2218-2232.

Kim, K.-J., Lim, C.-H., Heo, J.-Y., Lee, D.-H.H., Hong, Y.-S. and Park, K. (2013), "An evaluation scheme for product-service system models with a lifecycle consideration from customer's perspective", *in Re-Engineering Manufacturing for Sustainability*, pp. 69-74.

Kindström, D. (2010), "Towards a service-based business model – key aspects for future competitive advantage", *European Management Journal*, Vol. 28 No. 6, pp. 479-490.

Kjaer, L.L., Pagoropoulos, A., Schmidt, J.H. and McAloone, T.C. (2016), "Challenges when evaluating product/service-systems through life cycle assessment", *Journal of Cleaner Production*, Vol. 120, pp. 95-104.

Kohtamäki, M., Parida, V., Oghazi, P., Gebauer, H. and Baines, T. (2019), "Digital servitization business models in ecosystems: a theory of the firm", *Journal of Business Research*, Vol. 104, pp. 380-392.

Kowalkowski, C., Windahl, C., Kindström, D. and Gebauer, H. (2015), "What service transition? Rethinking established assumptions about manufacturers' service-led growth strategies", *Industrial Marketing Management*, Vol. 45, pp. 59-69.

Krucken, L. and Meroni, A. (2006), "Building stakeholder networks to develop and deliver product-service-systems: practical experiences on elaborating pro-active materials for communication", *Journal of Cleaner Production*, Vol. 14 No. 17, pp. 1502-1508.

Kuo, T.C. (2011), "Simulation of purchase or rental decision-making based on product service system", *International Journal of Advanced Manufacturing Technology*, Vol. 52 Nos 9–12, pp. 1239-1249.

Lee, S., Geum, Y., Lee, H. and Park, Y. (2012), "Dynamic and multidimensional measurement of product-service system (PSS) sustainability: a triple bottom line (TBL)-based system dynamics approach", *Journal of Cleaner Production*, Vol. 32, pp. 173-182.

Lee, H., Seo, H. and Geum, Y. (2018), "Uncovering the topic landscape of product-service system research: from sustainability to value creation", *Sustainability*, Vol. 10 No. 4, p. 911.

Lee, C.-H., Chen, C.-H. and Trappey, A.J.C. (2019), "A structural service innovation approach for designing smart product service systems: case study of smart beauty service", *Advanced Engineering Informatics*, Vol. 40, pp. 154-167.

Léo, P.-Y. and Philippe, J. (2001), "Offer of services by goods exporters: strategic and marketing dimensions", *The Service Industries Journal*, Vol. 21 No. 2, pp. 91-116.

Lerch, C. and Gotsch, M. (2015), "Digitalized product-service systems in manufacturing firms : a case study analysis", *Research Technology Management*, Vol. 58 No. 5, pp. 45-52.

Li, A.Q., Kumar, M., Claes, B. and Found, P. (2020), "The state-of-the-art of the theory on Product-Service Systems", *International Journal of Production Economics*, Vol. 222, p. 107491.

Lightfoot, H., Baines, T. and Smart, P. (2013), "The servitization of manufacturing: a systematic literature review of interdependent trends", *International Journal of Operations and Production Management*, Vol. 33 No. 11, pp. 1408-1434.

Lim, C.-H., Kim, K.-J., Hong, Y.-S. and Park, K. (2012), "PSS Board: a structured tool for product-service system process visualization", *Journal of Cleaner Production*, Vol. 37, pp. 42-53.

Lindahl, M., Sundin, E. and Sakao, T. (2014), "Environmental and economic benefits of Integrated Product Service Offerings quantified with real business cases", *Journal of Cleaner Production*, Vol. 64, pp. 288-296.

Lingegård, S. and Lindahl, M. (2015), "Integrated product service offerings for rail infrastructure–benefits and challenges regarding knowledge transfer and cultural change in a Swedish case", *Journal of Cleaner Production*, Vol. 98, pp. 166-174.

Liu, B., Zhang, Y., Zhang, G. and Zheng, P. (2019a), "Edge-cloud orchestration driven industrial smart product-service systems solution design based on CPS and IIoT", *Advanced Engineering Informatics*, Vol. 42, p. 100984.

Liu, Z., Ming, X. and Song, W. (2019b), "A framework integrating interval-valued hesitant fuzzy DEMATEL method to capture and evaluate co-creative value propositions for smart PSS", *Journal of Cleaner Production*, Vol. 215, pp. 611-625.

Lu, D., Lai, I.K.W. and Liu, Y. (2019), "The consumer acceptance of smart product-service systems in sharing economy: the effects of perceived interactivity and particularity", *Sustainability (Switzerland)*, Vol. 11 No. 3, p. 928.

Mahut, F., Daaboul, J., Bricogne, M. and Eynard, B. (2017), "Product-Service Systems for servitization of the automotive industry: a literature review", *International Journal of Production Research*, Vol. 55 No. 7, pp. 2102-2120.

Manzini, E. and Vezzoli, C. (2003), "A strategic design approach to develop sustainable product service systems: examples taken from the 'environmentally friendly innovation' Italian prize", *Journal of Cleaner Production*, Vol. 11 No. 8, pp. 851-857.

Martinez, V., Bastl, M., Kingston, J. and Evans, S. (2010), "Challenges in transforming manufacturing organisations into product-service providers", *Journal of Manufacturing Technology Management*, Vol. 21 No. 4, pp. 449-469.

Mastrogiacomo, Barravecchia, F. and Franceschini, F. (2019), "A worldwide survey on manufacturing servitization", *The International Journal of Advanced Manufacturing Technology*, Vol. 103, pp. 3927-3942.

Mastrogiacomo, Barravecchia, F. and Franceschini, F. (2020a), "Definition of a conceptual scale of servitization: proposal and preliminary results", *CIRP Journal of Manufacturing Science and Technology*, Vol. 29 Part B, pp. 141-156.

Mastrogiacomo, Barravecchia, F. and Franceschini, F. (2020b), "Enabling factors of manufacturing servitization: empirical analysis and implications for strategic positioning", *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, Vol. 234 No. 9, pp. 1258-1270.

Mastrogiacomo, L., Barravecchia, F., Franceschini, F. and Marimon, F. (2021), "Mining quality determinants of product-service systems from unstructured user-generated contents: the case of car-sharing", *Quality Engineering*, In press, doi: 10.1080/08982112.2021.1877305.

Mathieu, V. (2001), "Service strategies within the manufacturing sector: benefits, costs and partnership", *International Journal of Service Industry Management*, Vol. 12 No. 5, pp. 451-475.

Matschewsky, J., Lindahl, M. and Sakao, T. (2020), "Capturing and enhancing provider value in product-service systems throughout the lifecycle: a systematic approach", *CIRP Journal of Manufacturing Science and Technology*, Vol. 29 Part B, pp. 191-204.

Maussang, N., Zwolinski, P. and Brissaud, D. (2009), "Product-service system design methodology: from the PSS architecture design to the products specifications", *Journal of Engineering Design*, Vol. 20 No. 4, pp. 349-366.

Maxwell, D., Sheate, W. and van der Vorst, R. (2006), "Functional and systems aspects of the sustainable product and service development approach for industry", *Journal of Cleaner Production*, Vol. 14 No. 17, pp. 1466-1479.

Meier, H., Roy, R. and Seliger, G. (2010), "Industrial Product-Service Systems-IPS2", *CIRP Annals - Manufacturing Technology*, Vol. 59 No. 2, pp. 607-627.

Meier, H., Völker, O. and Funke, B. (2011), "Industrial Product-Service Systems (IPS2) : paradigm shift by mutually determined products and services", *International Journal of Advanced Manufacturing Technology*, Vol. 52 Nos 9–12, pp. 1175-1191.

Meyer, D., Hornik, K. and Feinerer, I. (2008), "Text mining infrastructure in R", *Journal of Statistical Software*, Vol. 25 No. 5, pp. 1-54.

Mont, O. and Tukker, A. (2006), "Product-Service Systems: reviewing achievements and refining the research agenda", *Journal of Cleaner Production*, Vol. 14 No. 17, pp. 1451-1454.

Morelli, N. (2006), "Developing new product service systems (PSS): methodologies and operational tools", *Journal of Cleaner Production*, Vol. 14 No. 17, pp. 1495-1501.

Morelli, N. (2009), "Service as value co-production: reframing the service design process", *Journal of Manufacturing Technology Management*, Vol. 20 No. 5, pp. 568-590.

Moro, S., Cauchick-Migue, P.A. and de Sousa Mendes, G.H. (2020), "Product-service systems benefits and barriers: an overview of literature review papers", *International Journal of Industrial Engineering and Management*, Vol. 11 No. 1, pp. 61-70.

Mourtzis, D., Fotia, S. and Vlachou, E. (2017), "Lean rules extraction methodology for lean PSS design via key performance indicators monitoring", *Journal of Manufacturing Systems*, Vol. 42, pp. 233-243.

Mourtzis, D., Fotia, S., Boli, N. and Vlachou, E. (2018), "An approach for the modelling and quantification of PSS customisation", *International Journal of Production Research*, Vol. 56 No. 3, pp. 1137-1153.

Neely, A. (2009), "Exploring the financial consequences of the servitization of manufacturing", *Operations Management Research*, Vol. 1 No. 2, pp. 103-118.

Ng, I.C.L., Maull, R. and Yip, N. (2009), "Outcome-based contracts as a driver for systems thinking and service-dominant logic in service science: evidence from the defence industry", *European Management Journal*, Vol. 27 No. 6, pp. 377-387.

Opresnik, D. and Taisch, M. (2015), "The value of big data in servitization", *International Journal of Production Economics*, Vol. 165, pp. 174-184.

Pan, J.-N. and Nguyen, H.T.N. (2015), "Achieving customer satisfaction through product-service systems", *European Journal of Operational Research*, Vol. 247 No. 1, pp. 179-190.

Panetta, K. (2019), *Gartner Top 10 Strategic Technology Trends for 2020*, available at: https://www.gartner.com/smarterwithgartner/gartner-top-10-strategic-technology-trends-for-2020/.

Parida, V., Sjödin, D.R., Wincent, J. and Kohtamäki, M. (2014), "Mastering the transition to product-service provision: insights into business models, Learning activities, and capabilities", *Research Technology Management*, Vol. 57 No. 3, pp. 44-52.

Pereira, V.R., Kreye, M.E. and Carvalho, M.M. (2019), "Customer-pulled and provider-pushed pathways for product-service system: the contingent effect of the business ecosystems", *Journal of Manufacturing Technology Management*, Vol. 30 No. 4, pp. 729-747.

Pezzotta, G., Cavalieri, S. and Gaiardelli, P. (2012), "A spiral process model to engineer a product service system: an explorative analysis through case studies", *CIRP Journal of Manufacturing Science and Technology*, Vol. 5 No. 3, pp. 214-225.

Pezzotta, G., Pirola, F., Rondini, A., Pinto, R. and Ouertani, M.-Z. (2016), "Towards a methodology to engineer industrial product-service system – evidence from power and automation industry", *CIRP Journal of Manufacturing Science and Technology*, Vol. 15, pp. 19-32.

Pezzotta, G., Sassanelli, C., Pirola, F., Sala, R., Rossi, M., Fotia, S., Koutoupes, A., Terzi, S. and Mourtzis, D. (2018), "The product service system lean design methodology (PSSLDM) integrating product and service components along the whole PSS lifecycle", *Journal of Manufacturing Technology Management*, Vol. 29 No. 8, pp. 1270-1295.

Pialot, O., Millet, D. and Bisiaux, J. (2017), "'Upgradable PSS': clarifying a new concept of sustainable consumption/production based on upgradablility", *Journal of Cleaner Production*, Vol. 141, pp. 538-550.

Qu, M., Yu, S., Chen, D., Chu, J. and Tian, B. (2016), "State-of-the-art of design, evaluation, and operation methodologies in product service systems", *Computers in Industry*, Vol. 77, pp. 1-14.

Reim, W., Parida, V. and Örtqvist, D. (2015), "Product-Service Systems (PSS) business models and tactics - a systematic literature review", *Journal of Cleaner Production*, Vol. 97, pp. 61-75.

Rodríguez, A.E., Pezzotta, G., Pinto, R. and Romero, D. (2020), "A comprehensive description of the product-service systems' cost estimation process: an integrative review", *International Journal of Production Economics*, Vol. 221, 107481.

Rondini, A., Tornese, F., Gnoni, M.G., Pezzotta, G. and Pinto, R. (2017), "Hybrid simulation modelling as a supporting tool for sustainable product service systems: a critical analysis", *International Journal of Production Research*, Vol. 55 No. 23, pp. 6932-6945.

Rondini, A., Bertoni, M. and Pezzotta, G. (2020), "At the origins of product service systems: supporting the concept assessment with the engineering value assessment method", *CIRP Journal of Manufacturing Science and Technology*, Vol. 29 Part B, pp. 157-175.

Roy, R. (2000), "Sustainable product-service systems", *Futures*, Vol. 32 Nos 3–4, pp. 289-299.

Roy, R. and Cheruvu, K.S. (2009), "A competitive framework for industrial product-service systems", *International Journal of Internet Manufacturing and Services*, Vol. 2 No. 1, pp. 4-29.

Sakao, T. (2019), "Research series review for transdisciplinarity assessment-validation with sustainable consumption and production research", *Sustainability (Switzerland)*, Vol. 11 No. 19, p. 5250.

Sakao, T. and Lindahl, M. (2012), "A value based evaluation method for product/service system using design information", *CIRP Annals - Manufacturing Technology*, Vol. 61 No. 1, pp. 51-54.

Salazar, C., Lelah, A. and Brissaud, D. (2015), "Eco-designing product service systems by degrading functions while maintaining user satisfaction", *Journal of Cleaner Production*, Vol. 87, pp. 452-462.

Schweitzer, E. and Aurich, J.C. (2010), "Continuous improvement of industrial product-service systems", *CIRP Journal of Manufacturing Science and Technology*, Vol. 3 No. 2, pp. 158-164.

Scopus Elsevier (2020), *Scopus Content Converage*, available at: http://www.scopus.com (accessed 15 January 2020).

Shao, S., Xu, G. and Li, M. (2019), "The design of an IoT-based route optimization system: a smart product-service system (SPSS) approach", *Advanced Engineering Informatics*, Vol. 42, pp. 1-9.

Shimomura, Y., Hara, T. and Arai, T. (2009), "A unified representation scheme for effective PSS development", *CIRP Annals - Manufacturing Technology*, Vol. 58 No. 1, pp. 379-382.

Shimomura, Y., Nemoto, Y. and Kimita, K. (2015), "A method for analysing conceptual design process of product-service systems", *CIRP Annals - Manufacturing Technology*, Vol. 64 No. 1, pp. 145-148.

Shimomura, Y., Nemoto, Y., Ishii, T. and Nakamura, T. (2018), "A method for identifying customer orientations and requirements for product–service systems design", *International Journal of Production Research*, Vol. 56 No. 7, pp. 2585-2595.

Sholihah, M., Maezono, T., Mitake, Y. and Shimomura, Y. (2019), "PSS strategic alignment: linking service transition strategy with PSS business model", *Sustainability*, Vol. 11 No. 22, p. 6245.

Song, W. (2017), "Requirement management for product-service systems: status review and future trends", *Computers in Industry*, Vol. 85, pp. 11-22.

Song, W. and Sakao, T. (2017), "A customization-oriented framework for design of sustainable product/service system", *Journal of Cleaner Production*, Vol. 140 Part 3, pp. 1672-1685.

Song, W., Ming, X., Han, Y. and Wu, Z. (2013), "A rough set approach for evaluating vague customer requirement of industrial product-service system", *International Journal of Production Research*, Vol. 51 No. 22, pp. 6681-6701.

Sousa-Zomer, T.T. and Miguel, P.A.C. (2018), "The main challenges for social life cycle assessment (SLCA) to support the social impacts analysis of product-service systems", *The International Journal of Life Cycle Assessment*, Vol. 23 No. 3, pp. 607-616.

Takenaka, T., Yamamoto, Y., Fukuda, K., Kimura, A. and Ueda, K. (2016), "Enhancing products and services using smart appliance networks", *CIRP Annals - Manufacturing Technology*, Vol. 65 No. 1, pp. 397-400.

Tukker, A. (2004), "Eight types of product-service system: eight ways to sustainability? Experiences from suspronet", *Business Strategy and the Environment*, Vol. 13 No. 4, pp. 246-260.

Tukker, A. (2015), "Product services for a resource-efficient and circular economy - a review", *Journal of Cleaner Production*, Vol. 97, pp. 76-91.

Tukker, A. and Tischner, U. (2006), "Product-services as a research field: past, present and future. Reflections from a decade of research", *Journal of Cleaner Production*, Vol. 14 No. 17, pp. 1552-1556.

Ulaga, W. and Reinartz, W.J. (2011), "Hybrid offerings: how manufacturing firms combine goods and services successfully", *Journal of Marketing*, Vol. 75 No. 6, pp. 5-23.

Valencia, A., Mugge, R., Schoormans, J.P.L. and Schifferstein, H.N.J. (2015), "The design of smart product-service systems (PSSs): an exploration of design characteristics", *International Journal of Design*, Vol. 9 No. 1, pp. 13-28.

Vasantha, G.V.A., Roy, R., Lelah, A. and Brissaud, D. (2012), "A review of product-service systems design methodologies", *Journal of Engineering Design*, Vol. 23 No. 9, pp. 635-659.

Vezzoli, C., Ceschin, F., Diehl, J.C. and Kohtala, C. (2015), "New design challenges to widely implement 'Sustainable Product-Service Systems'", *Journal of Cleaner Production*, Vol. 97, pp. 1-12.

Visnjic Kastalli, I. and Van Looy, B. (2013), "Servitization: disentangling the impact of service business model innovation on manufacturing firm performance", *Journal of Operations Management*, Vol. 31 No. 4, pp. 169-180.

Wallin, J., Parida, V. and Isaksson, O. (2015), "Understanding product-service system innovation capabilities development for manufacturing companies", *Journal of Manufacturing Technology Management*, Vol. 26 No. 5, pp. 763-787.

Wang, P.P., Ming, X.G., Li, D., Kong, F.B., Wang, L. and Wu, Z.Y. (2011), "Status review and research strategies on product-service systems", *International Journal of Production Research*, Vol. 49 No. 22, pp. 6863-6883.

Wang, W., Zhou, F., Li, W. and Budd, J. (2018), "Designing the product-service system for autonomous vehicles", *IT Professional*, Vol. 20 No. 6, pp. 62-69.

Wang, Z., Chen, C.-H., Zheng, P., Li, X. and Khoo, L.P. (2019), "A graph-based context-aware requirement elicitation approach in smart product-service systems", *International Journal of Production Research*, pp. 1-17, doi: 10.1080/00207543.2019.1702227.

Wiesner, S., Marilungo, E. and Thoben, K.-D. (2017), "Cyber-physical product-service systems – challenges for requirements engineering", *International Journal of Automation Technology*, Vol. 11 No. 1, pp. 17-28.

Yang, M. and Evans, S. (2019), "Product-service system business model archetypes and sustainability", *Journal of Cleaner Production*, Vol. 220, pp. 1156-1166.

Yang, M., Evans, S., Vladimirova, D. and Rana, P. (2017), "Value uncaptured perspective for sustainable business model innovation", *Journal of Cleaner Production*, Vol. 140 Part 3, pp. 1794-1804.

Zancul, E.D.S., Takey, S.M., Barquet, A.P.B., Kuwabara, L.H., Cauchick Miguel, P.A. and Rozenfeld, H. (2016), "Business process support for IoT based product-service systems (PSS)", *Business Process Management Journal*, Vol. 22 No. 2, pp. 305-323.

Zheng, P., Lin, T.-J., Chen, C.-H. and Xu, X. (2018), "A systematic design approach for service innovation of smart product-service systems", *Journal of Cleaner Production*, Vol. 201, pp. 657-667.

Zheng, P., Wang, Z., Chen, C.-H. and Khoo, L.P. (2019), "A survey of smart product-service systems: key aspects, challenges and future perspectives", *Advanced Engineering Informatics*, Vol. 42, p. 100973.

Zhu, Q.Q., Jiang, P.Y., Huang, G.Q. and Qu, T. (2011), "Implementing an industrial product-service system for CNC machine tool", *International Journal of Advanced Manufacturing Technology*, Vol. 52 Nos 9–12, pp. 1133-1147.

Ziaee Bigdeli, A., Baines, T., Schroeder, A., Brown, S., Musson, E., Guang Shi, V. and Calabrese, A. (2018), "Measuring servitization progress and outcome: the case of 'advanced services", *Production Planning and Control*, Vol. 29 No. 4, pp. 315-332.

About the authors

Federico Barravecchia is a Postdoctoral Researcher at the Department of Management and Production Engineering at Politecnico di Torino. His main scientific interests currently concern the areas of Product-Servic Systems, Service Quality and Quality Engineering.

Fiorenzo Franceschini is a Professor of Quality Engineering at Politecnico di Torino (Italy) – Department of Management and Production Engineering. He is author or coauthor of 9 books and more than 270 many published papers in prestigious scientific journals and international conference proceedings. His current research interests are in the areas of Product-Service Systems, Quality

Engineering and Performance Measurements Systems. Fiorenzo Franceschini is the corresponding author and can be contacted at: fiorenzo.franceschini@polito.it

Luca Mastrogiacomo is an Associate Professor at the Department of Management and Production Engineering at Politecnico di Torino. His main scientific interests currently concern the areas of Product-Service Systems and Quality Engineering.

Mohamed Zaki is the Deputy Director of the Cambridge Service Alliance at the University of Cambridge (UK), a research center that brings together the world's leading firms and academics to address service challenges. Mohamed's research interests lie in the field of machine learning and its application on Digital Manufacturing and services. He uses an interdisciplinary approach of data science techniques to address a range of real organizations' problems such as measuring and managing customer experience and customer loyalty. Other research interests include digital service transformation strategy and data-driven business models.

For instructions on how to order reprints of this article, please visit our website:
www.emeraldgrouppublishing.com/licensing/reprints.htm
Or contact us for further details: **permissions@emeraldinsight.com**