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Investigating social and environmental hotspots throughout the lifecycle of product-service systems in the early design stages

Thayla Tavares Sousa Zomer [a,b,*], Paulo Augusto Cauchick-Miguel [b,c], Eloiza Kohlbeck [d], Suzana Regina Moro [e], Eduardo de Senzi Zancul [b], Glauco Henrique de Sousa Mendes [f]

[a] Fundação Dom Cabral, Campus São Paulo, São Paulo, SP, Brazil
[b] Production Engineering Department, University of São Paulo, São Paulo, SP, Brazil
[c] Production Engineering Department, Federal University of Santa Catarina, SC, Brazil
[d] Graduate Program in Production, Federal University of Santa Catarina, SC, Brazil
[e] School of Mechanical Engineering, University of Campinas, Campinas, SP, Brazil
[f] Production Engineering Department, Federal University of São Carlos, São Carlos, SP, Brazil

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ABSTRACT

Product-Service Systems (PSS) have been recognized as potential game-changers for advancing sustainability. However, the sustainability of a PSS over traditional products and services is not automatic; it requires careful, intentional design. Despite a decade's progress in relevant literature, early-stage design assessment of a PSS – particularly from a life cycle standpoint and considering the social sustainability dimension – remains under-explored. This study introduces a framework for early-stage identification and analysis of potential environmental and social impacts within a PSS's life cycle to aid in decision-making and guide towards sustainable solutions. The framework's hotspot analysis, which combines life cycle assessment techniques, aims to pinpoint life cycle stages most susceptible to significant environmental and social impacts. Drawing on existing literature and expert evaluations, this approach offers designers preliminary insights into potential impacts, establishing a groundwork for comprehensive life cycle analysis once more detailed information on products, services, and organizational structures becomes available. The hotspot analysis not only addresses the lifecycle view of a PSS but also places emphasis on the oft-neglected social dimension of sustainability, marking an area ripe for further study. By supporting decision-making in the early design phase and encouraging scrutiny of various PSS concepts, this approach promotes the cultivation of sustainably-designed solutions.

1. Introduction

Product-Service Systems (PSS) are at the forefront of sustainability conversations, proposing a transformative approach to production and consumption (Mont, 2002; Tukker, 2015; Yang and Evans, 2019). A PSS delivers a cohesive mix of products and services, prioritizing functional value over mere product ownership (Neely, 2009). This transition towards a PSS model is synonymous with adopting a new, sustainable business paradigm (Van Opstal and Smeets, 2023), aligning with the triple bottom line framework—encompassing environmental, social, and economic aspects—to foster innovation for sustainability (Bocken et al., 2014). The integral value of a PSS in sustainable market offerings is well-documented (Goedkoop et al., 1999; Rosa et al., 2019). However, sustainability in PSS is not inherent; it requires strategic design (Vezzoli et al., 2015), as the design phase critically influences its potential for sustainability (Pigosso and McAloone, 2015; Vezzoli et al., 2015). Thus, it is important to focus on the design stage of the PSS lifecycle, where digital technologies represent a driver enabling knowledge acquisition and continuous improvement (Sassanelli et al.,2019a,b).

While the sustainable promise of PSS is acknowledged, research on their holistic, sustainable value – especially in social sustainability – is limited (Moro et al., 2022). Existing studies often qualitatively assess a PSS's environmental impact reductions, like resource use (Lee et al., 2012), but fall short in evaluating the broader gains in environmental, economic, and social spheres (Moro et al., 2022). The literature reveals an imperative for tools to gauge PSS sustainability early in the design process (Fernandes et al., 2020), as initial design decisions are crucial for embedding sustainability (Zhang et al., 2021). An in-depth analysis

* Corresponding author. Fundação Dom Cabral, Campus São Paulo, São Paulo, SP, Brazil.
E-mail addresses: thayla.zomer@fdc.org.br, thayla.zomer@usp.br (T.T. Sousa Zomer).

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from the start, including all three sustainability dimensions, ensures a PSS's impacts don't inadvertently escalate over its lifecycle, including maintenance (Amaya et al., 2014). Furthermore, the collective impact on all stakeholders within the PSS lifecycle merits consideration (Kristensen and Remmen, 2019). Early assessment of PSS concepts is vital, as improper selection can lead to resource inefficiency and economic losses (de Jesus Pacheco et al., 2019; Yang et al., 2024). A PSS assessment must take a holistic view, incorporating lifecycle stages and stakeholder perspectives, extending beyond economics to include environmental and social sustainability (Lee et al., 2012). Yet, the social impact often receives less emphasis (Corsini and Moultrie, 2021), and sustainable value should reflect intrinsic environmental worth, not just its economic translation (Manninen et al., 2018). Additionally, sustainable business model literature has overlooked small enterprises and startups (Henry et al., 2020), which face methodological gaps at the onset of PSS development (Kloock-Schreiber et al., 2020).

This research addresses the need for a comprehensive approach to support the initial design phase of a PSS, integrating environmental and social considerations for both small and large firms. Despite progress in PSS design literature, gaps remain, particularly in evaluating the early design stages concerning the social sustainability dimension (Yang et al., 2024). This study proposes a method to identify and analyze environmental and social impacts across a PSS's lifecycle at the design stage, aiming to guide system design towards minimizing adverse effects. By including social factors early on, this research augments the PSS knowledge base, which, while growing, still underrepresents the social aspect (Kristensen and Remmen, 2019), and is crucial for choosing the most sustainable PSS design.

This paper is structured into six sections: methodology, theoretical framework, development of the conceptual framework, expert assessment and refinement, discussion of findings, and future research directions.

2. Research design

This research offers a framework designed to pinpoint potential environmental and social hotspots within the lifecycle of product-service systems. It is intended for integration at the early stages of the PSS design process. The development of this framework adheres to the phases depicted in Fig. 1, which are outlined subsequently.

2.1. Literature analysis

A literature review was initially conducted, aiming to identify methods and tools for assessing the sustainable potential of a PSS in the design and identify whether and which environmental and social aspects have been considered by existing methods and tools. The literature review also supported the identification of studies addressing the life cycle of a PSS and the identification of the phases/stages of a PSS life cycle, as it differs from the life cycle of a product for also involving a service. In other words, the literature review aimed at both informing the theoretical development of the framework and identifying previous research on the topic. To this end, the stages of identification, screening, eligibility, and inclusion of articles in the literature were considered, as proposed by Moher et al. (2009).

Only peer-reviewed articles were considered in the review. The Scopus database was employed and the main source for the articles, for indexing journals in the areas of interest of this research and also for being used by previous publications in the PSS field (e.g. Tukker, 2015). Table 1 summarizes the keywords used to perform the search, which was conducted in titles, abstracts and keywords. Keywords related to lifecycle assessment were also included in the search, considering the focus of this study.

Only papers that addressed methods and tools for assessing PSS sustainability potential during the design stage and that addressed PSS from a lifecycle perspective were considered.

A content analysis was carried out, recognized for its efficacy in dissecting the literature within a specific domain (Harkonen et al., 2015). The literature on PSS design is extensive and includes various methods and tools to support the development of PSS solutions. Some proposed approaches include: (i) GuRu, a methodology providing technical and design guidance for PSS (Sassanelli et al., 2019a,b); (ii) the Product-Service Concept Tree (PSCT) method, aimed at identifying PSS solutions and generating an assessment of the best implementation option (Rondini et al., 2016); (iii) a Service Engineering Methodology (SEEM), which strategically supports companies in introducing PSSs into their portfolio (Pezzotta et al., 2016); and (iv) Design for Product-Service Support (DfPSS) by Sassanelli et al. (2016). Existing contributions converge towards the following phases: (i) a strategic phase that encompasses needs identification, requirements definition, strategic positioning coupled with the PSS conceptual design phase (ending with the selection of a PSS concept); (ii) a product/service design phase seen as a PSS detailed design phase, involving concept development, embodiment design, and detailed design or sub-systems identification and integration; and (iii) an implementation phase (Trevisan and Brissaud, 2016). However, as highlighted by Trevisan and

Table 1
Keywords and results of the literature analysis (May 2024).

Keywords	Search results
(TITLE-ABS-KEY ("Lifecycle assessment") OR TITLE-ABS-KEY ("lifecycle analysis") OR TITLE-ABS-KEY ("sustainability assessment") OR TITLE-ABS-KEY ("environmental assessment") OR TITLE-ABS-KEY ("environmental analysis") OR TITLE-ABS-KEY ("sustainability analysis") AND TITLE-ABS-KEY ("product-service systems") (TITLE-ABS-KEY ("sustainability") OR TITLE-ABS-KEY ("sustainable design") OR TITLE-ABS-KEY ("environmental impacts") AND TITLE-ABS-KEY ("product-service systems development") OR TITLE-ABS-KEY ("product-service system design"))	44 articles
(TITLE-ABS-KEY ("Lifecycle") OR TITLE-ABS-KEY ("life cycle") AND TITLE-ABS-KEY ("product-service systems"))	268 articles

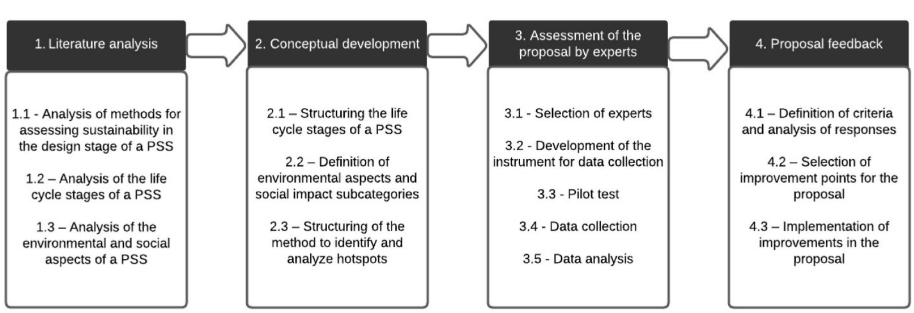

Fig. 1. Stages of the research.

Brissaud (2016), the intricate steps within each stage are usually not well clarified, and there are few tools for guiding the PSS design from concept selection to the most detailed levels of solution definition, such as those proposed by Sassanelli et al., 2019a,b.

Pieroni et al. (2017), in a review of various PSS design methods, also concluded that very few design approaches actually support sustainable PSS design. More recently, other publications have asserted that sustainable PSS offerings can only be achieved through purposeful design (Zhou et al., 2024), and that the ideation stage directs how the design of a sustainable PSS would follow, which also largely depends on the firm's strategic vision (Naor et al., 2018). Previous studies, such as those by Sassanelli et al., 2019a,b, provide technical directions and design ideas to follow during design, but existing approaches still lack recommendations on the detailed activities within the design towards developing sustainable PSS offers, such as how to assess different PSS ideas/concepts from a sustainability perspective.

Despite some approaches developed in the past to support the design of sustainable PSS solutions, there is still a lack of suitable methods for assessing PSS concepts. This includes identifying and analyzing potential environmental and social impacts across the lifecycle of a PSS solution during the early design stages, before the concept alternatives are effectively defined, and from both environmental and social perspectives. One of the approaches briefly mentioned across the publications and also found in the product domain literature that could be suitable for assessing a PSS from both environmental and social perspectives is hotspot analysis (UNEP/SETAC, 2014). This approach was found fitting for this research's purpose: (i) for considering the social dimension, which is notably lacking in PSS research, and (ii) for supporting analysis from a lifecycle perspective in the initial design stages. Indeed, hotspot analysis allows identifying critical points of sustainability-related themes throughout the lifecycle (Liedtke et al., 2010) and can be applied during design, before the solution is conceived. Several companies have adopted this methodology to identify areas for action across products' lifecycle (Liedtke et al., 2010). Thus, hotspot analysis was considered a suitable approach for application in the PSS context as well. This study's hotspot analysis incorporates both environmental and social dimensions. The economic dimension is often tied to the strategic profile of the participating organizations and is usually already considered by designers when developing new solutions, thus it was not the focus here.

Some additional sources (e.g., UNEP/SETAC, 2014), which are recognized as some of the main references in social lifecycle analysis were then analyzed to support the adaptation of the hotspot analysis for the PSS context. Pertinent initiatives and reports by the Life Cycle Initiative, a collaboration between the Society of Environmental Toxicology and Chemistry (SETAC) and the United Nations Environment Programme (UNEP) we consulted. Those were included due to their significance, especially considering the rarity of social perspective life cycle studies (Chhipi-Shrestha et al., 2015). Of the various product-level hotspot analyses found among those sources, the approach by the Wuppertal Institute (Sustainability Hotspots Analysis - SHSA) was deemed appropriate for product/service evaluation, particularly in its treatment of the social dimension.

The Social Life Cycle Assessment (SLCA) represents another method at the product level that encompasses the social aspect (UNEP/SETAC, 2009). UNEP/SETAC (2014) surveys found SLCA's hotspot analysis to be "essential" for achieving its goals. Given that both hotspot analysis methods incorporate the social dimension, and the Sustainability Hotspots Analysis also accounts for the environmental dimension, their combined attributes offer a robust starting point. This synergy laid the groundwork for developing a hotspot analysis tailored to the nuances of a PSS, as detailed next.

2.2. Conceptual development

The hotspot analysis approach for Product-Service Systems (PSS) begins by outlining the PSS lifecycle structure. The initial methodologies applied—Sustainability Hotspots Analysis and SLCA's perspective—incorporate both environmental and social elements (as per the Sustainability Hotspots Analysis) and social impact categories (as per the SLCA's hotspot analysis). These elements were then specified within our proposed approach. In selecting social impact subcategories according to UNEP/SETAC guidelines (the starting point), we used two criteria: (i) subcategories should extend beyond just the behaviors of the organizations, linking instead to the processes, business model, and lifecycle stages; (ii) subcategories must be broad enough to evaluate any type of PSS, aligning with Tukker's (2004) PSS classification. Because UNEP/SETAC (2009) generally ties impact subcategories to organizational behavior, which is undefined in early design stages, we chose only those subcategories without this limitation, mirroring the approach by Lehmann et al. (2013).

For the environmental dimension, aspects for inclusion in the hotspot approach were discerned from the PSS sustainability literature and analyses of hotspots. We sifted through the PSS literature, selecting studies that evaluate the sustainability potential of PSS. The environmental aspects these studies considered were cataloged. We then chose those aspects mentioned in two or more studies, which are sufficiently generic for use in designing any PSS category and are discussed in hotspot analysis literature.

With the environmental and social aspects established, their analysis must span the entire PSS lifecycle. The analysis followed a systematic method in line with the procedures proposed by the Sustainability Hotspot Analysis – SHSA (UNEP/SETAC, 2014).

2.3. Assessment of the hotspot approach by experts

A survey was crafted to evaluate the hotspot-based methodology developed by experts in the field of Product-Service Systems. The survey design process involved a series of stages with expert consultation, as follows: (i) expert selection; (ii) creation of the data gathering tool; (iii) a preliminary pilot test; (iv) the actual data collection; and (v) analysis of the data.

Experts were chosen based on specific qualifications: (i) possession of a PhD; (ii) authorship of publications on sustainability assessment and/or life cycle assessment within PSS; or (iii) participation in international projects on the relevant subject. A total of 16 researchers were initially pre-selected as possible participants (details of which are provided in Table 2). The survey consisted of 40 multiple-choice questions, distributed across five distinct sections, exploring various facets of the introduced method.

Table 2
– Researchers selected to evaluate the proposal.

Researcher	Affiliation	Country	Main research topic
1	Federal University of Paraná	Brazil	PSS
2	Grenoble Institute of Technology	France	PSS, LCA
3	University of São Paulo	Brazil	LCA
4	Technische Universität Berlin	Germany	PSS
5	Technical University of Denmark	Denmark	PSS
6	Santa Catarina State University	Brazil	PSS
7	Federal University of São Carlos	Brazil	PSS
8	University of São Paulo	Brazil	PSS
9	Delf University of Technology	Netherlands	PSS
10	Grenoble Institute of Technology	France	PSS, LCA
11	École Nationale Supérieure des Mines de Saint-Étienne	France	PSS
12	Technical University of Denmark	Denmark	PSS, LCA
13	Santa Catarina State University	Brazil	PSS
14	Grenoble Institute of Technology	France	PSS, LCA
15	Pontifical Catholic University of Paraná	Brazil	Social LCA
16	United Nations Environment Programme	Brazil	Social LCA

The evaluation was anchored in criteria established by Vernadat (1996), which included: i) utility; ii) completeness; iii) scope; iv) comprehensiveness; v) depth; vi) simplicity; vii) clarity; viii) objectivity; ix) forecasting ability; and x) measurement. This approach was scrutinized for its practicability in the preliminary design phase of a PSS, ease of use during design, the chosen measurement metrics to ascertain potential life cycle impacts, and its effectiveness in analyzing various PSS categories at the initial design stage, fostering a comprehensive perspective on potential life cycle impacts.

The research team, along with an external expert, carried out a preliminary pilot test of the questionnaire to ensure clarity, scope, and comprehensive coverage of the necessary aspects for assessing the viability of the proposed hotspot approach during the design phases. Following the feedback received, refinements were made to enhance the question presentation. The finalized questionnaire was then distributed via Google Forms, and the identified researchers were invited to participate through email communications. After consulting with the experts, we concluded that it was not necessary to include more participants, as the feedback provided were repeating among the respondents, showing saturation in the responses.

2.4. Improvements in the original hotspot approach

The initial hotspot approach was refined by incorporating expert feedback that met the following criteria: (i) consistency with Product-Service Systems (PSS) literature, and/or (ii) alignment with other streamlined life cycle assessment methods during the design process. Suggestions made by multiple respondents were automatically flagged for analysis.

Further, any recommendations to include subcategories of social or environmental impact had to be broadly applicable across various PSS offers, as per Tukker's (2004) classification, and adhere to previously established criteria. If a suggestion pertained to the removal of a subcategory, it was evaluated to ensure it did not contradict the rationale for its initial inclusion. Where there was such a contradiction, the expert's advice was adopted.

When addressing structural elements of the proposed approach, those aspects that the majority of experts deemed "neither unsatisfactory nor satisfactory" were compared against other methods identified in the literature review. For instance, when experts provided neutral feedback on the clarity of hotspot identification, we consulted literature on simplified life cycle assessment methods in design, such as checklists used in ERPA and MET-Matrix (Brezet and Hemel, 1997), to enhance our approach. Consequently, a checklist was developed to aid in the analysis and better pinpoint hotspots.

As for life cycle stages recommended by experts, these were incorporated only if they were consistent with both life cycle literature and PSS life cycle assessment.

3. Literature analysis

The findings from the literature review, which formed the foundation for developing the framework, are summarized in the following section.

3.1. Lifecycle of product-service systems

A Product-Service System must be strategically planned and devised with a thorough understanding of its lifecycle performance, particularly in terms of sustainability (Amaya et al., 2014). Key studies that have examined the development of a PSS alongside its lifecycle are outlined in Table 3.

Table 3
Studies addressing the life cycle of a PSS and its stages considered.

Life cycle stages of a PSS considered	References
Demand identification, feasibility analysis, concept development, service modeling, realization planning, service testing	Aurich et al. (2006)
Planning and development, manufacture of the product, carrying out the corresponding services	Aurich et al. (2009)
Manufacturing, maintenance, transportation, and remanufacturing	Sundin et al. (2009)
Manufacturing, transport, installation, and use	Lelah et al. (2011)
Planning, development, implementation, operation, and end-of-service life	Song et al. (2013)
Material extraction, product manufacturing, distribution, use (stand-by stages, use, and maintenance)	Amaya et al. (2014)
Concept definition, integrated design, production, implementation, creation, use, end of life	Peruzzini and Germani (2014)
Extraction, production, transport, sales, installation, use, maintenance, and disposal	Nemoto et al. (2015)
Ideation, requirements identification, design, realization, delivery, support, evolution	Wiesner et al. (2015)
Requirements definition, development, implementation, monitoring, and destination after use	Beuren et al. (2017)
Consumer analysis, solution concept design, solution final design, offering analysis	Pezzotta et al. (2018)

The lifecycle of a Product-Service System (PSS) encompasses three principal phases: (i) Beginning of Life (BoL), (ii) Middle of Life (MoL), and (iii) End of Life (EoL) as noted by Cavalieri et al. (2012). The considered lifecycle in this research initiates with the "ideation" phase, which involves the generation of an integrated product and service concept. Tran and Park (2016) assert that life cycle design strategies for a PSS should include stages of ideation, planning, defining requirements, developing concepts, detailed design, testing, implementation and support, disposal, and recycling. This study posits that the post-design stages of a PSS are significant for applying the proposed approach to identify lifecycle hotspots, particularly from the provider's perspective. This is attributed to the production phase being the source of major impacts, as suggested by Peruzzini and Germani (2014). Fig. 2, constructed from content analysis performed, offers a synopsis of the research landscape concerning Product-Service Systems and their sustainability potential.

3.2. Sustainability assessment of product-service systems

Evaluating the sustainability potential of Product-Service System (PSS) concepts during the design phase, particularly at the conceptual stage, is crucial for the development of sustainable PSS solutions. Table 4 compiles the studies that offer methodologies and instruments for appraising the sustainability aspects of a PSS.

The approach presented by Peruzzini and Germani (2014) stands out in the literature as applicable in the early design stages of a PSS, integrating considerations for the PSS lifecycle and the triad of sustainability dimensions. This method advocates for the use of life cycle assessment techniques tailored to the environmental, economic, and social pillars (LCA, LCC, and SLCA). However, it lacks a detailed methodological framework for conducting these assessments. Given the complexity of applying life cycle assessments to a PSS, which encompasses both products and services, merely proposing such techniques is insufficient for their practical implementation (Amaya et al., 2014).

Furthermore, centering design planning around the life cycle is crucial for realizing enhancements and minimizing impacts (Ramani et al., 2010). Even though LCA is recognized for its potential in evaluating PSS and has been employed in certain studies for this purpose (e.g., Amaya et al., 2014), performing a comprehensive LCA during the design phase, particularly in the initial stages, presents significant hurdles, similar to those in product design. The existing challenges are exacerbated by the lack of methodologies for assessing the impacts of unconventional life cycle strategies inherent in PSS, which include a mix of intangible and tangible elements (Kjaer et al., 2016). Consequently, there is a research gap in the life cycle assessment of PSS, especially from the social perspective and during the early design phases.

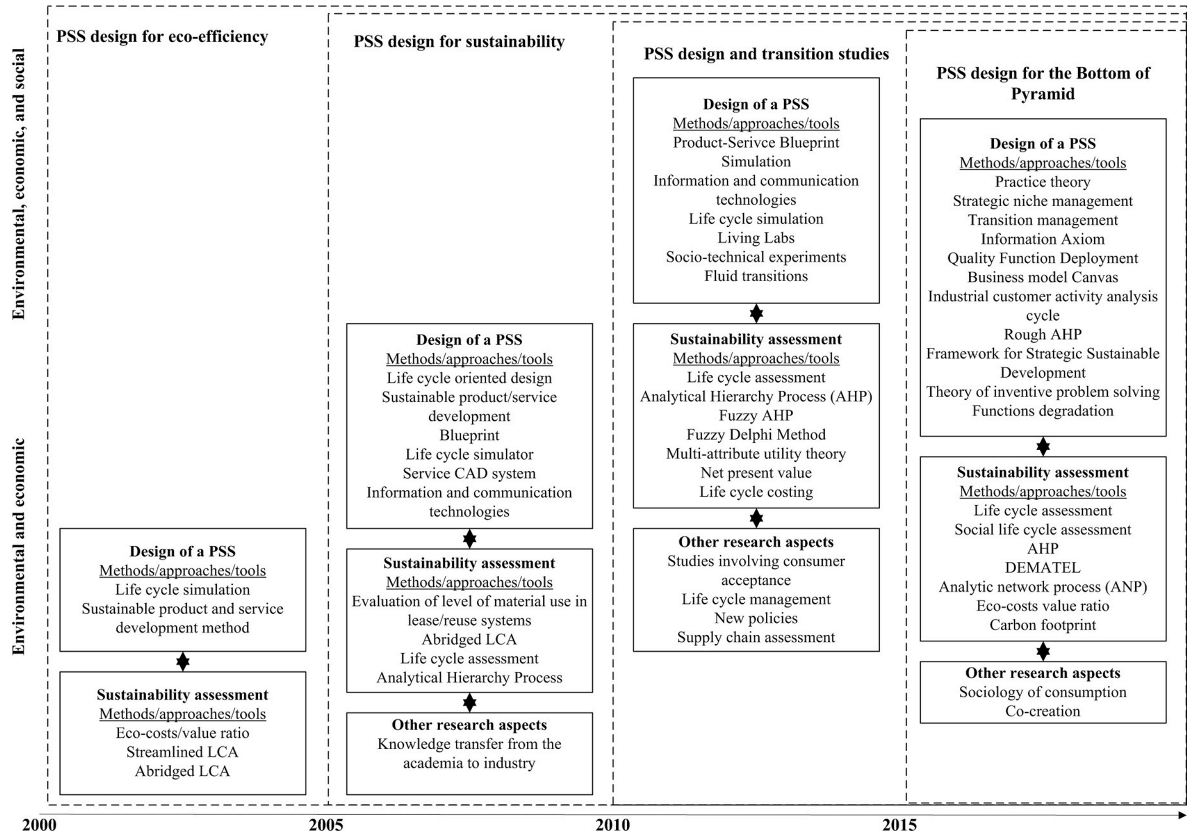

Fig. 2. Evolution of research on design and assessment of the sustainable potential of a PSS.

Table 4
Methods and tools for assessing the sustainability of Product-Service Systems.

Reference	Proposed methods/approaches	Sustainability dimensions considered			Application in the early stages of design	Life cycle perspective
		Env	Eco	Soc		
Lelah et al. (2011)	Analysis of the consequences of a PSS using the LCA	X				X
Hu et al. (2012)	Proposal considering several aspects and Fuzzy AHP to determine occasions a product or service is suitable for a PSS	X	X	X		
Lee et al. (2012)	Proposal using dynamic systems to assess multidimensional aspects of a PSS	X	X	X	X	
Amaya et al. (2014)	Proposal to adapt the LCA to assess the life cycle of a PSS	X			X	X
Peruzzini and Germani (2014)	Proposal for integration of various methods such as LCA and SLCA for application in the initial design stages	X	X	X	X	X
Chen et al. (2015)	Proposal to identify the criteria to be considered in each dimension during the assessment of a PSS and how to address aspects of uncertainty during the assessment	X	X	X	X	
Chou et al. (2015)	Proposal for a single and integrated index to assess the sustainability of a PSS	X	X	X		
Kim et al. (2016)	Proposal for assessing the sustainability of a PSS considering 94 indicators in the three dimensions	X	X	X	X	
Kjaer et al. (2016)	Analysis of the application of the LCA to assess a PSS considering three different scopes	X			X	X
Sousa-Zomer and Cauchick Miguel (2018)	Analysis of the applicability of the SLCA to assess the social impacts of a PSS			X		
Sarancic et al. (2022)	Development of a tool (BESST PSS) to support PSS decision-making based on the triple bottom line	X	X	X		X
Walk et al. (2023)	Using artificial intelligence to achieve cleaner production and sustainability, i.e., using smart PSS to achieve sustainable development	X	X	X		X

Note: Env – Environmental; Eco – Economic: Soc - Social.

3.3. *Methods and tools for assessing impacts throughout the life cycle during the design stages*

A variety of methods and tools aimed at evaluating sustainability and facilitating its integration into the design process have been proposed in scholarly articles. These include matrices, checklists, and sets of guidelines, which are detailed in Table 5.

Hallstedt et al. (2015) have emphasized the need for methods that account for both costs and social dimensions in addition to environmental concerns. Hotspot analysis serves as a tool to evaluate the

Table 5
Methods and tools for integration into the initial stages of design and considering the life cycle perspective.

Tool	Description	Sustainability dimensions	Reference
MET-Matrix	The purpose is to identify the most critical environmental problems during the life cycle, which can be used to define different improvement strategies	Environmental	Brezet and Hemel (1997)
LiDS-wheel	Provides an overview of the potential for product improvement. Environmental improvement strategies are proposed, and the reference product is analyzed according to such strategies	Environmental	Brezet and Hemel (1997)
Eco design checklist	Allows identifying the main environmental problems throughout the life cycle of a product. The user must assess whether the solutions are good, indifferent, poor, or irrelevant according to the proposed checklist	Environmental	Tischner et al. (2000)
ABC-Analysis	Allows environmental impacts to be assessed considering 11 criteria	Environmental	Tischner et al. (2000)
Strategy list	Allows for analyzing the environmental performance of the concept of a product or comparing different concepts. Consists of a list of suggestions for each stage of the life cycle to improve environmental performance	Environmental	Tischner et al. (2000)
Hotspot analysis	Allows a quick analysis of possible impacts throughout the life cycle using a variety of information sources	Environmental, economic, and social	UNEP/SETAC (2014)
Product Service System Lean Design Methodology (PSSLDM)	Structured methodology to develop PSS throughout their entire life cycle, considering Lean components	Economic, and environmental	Pezzotta et al. (2018)
Lifecycle-oriented function deployment (LFD)	Based on Life Cycle Assessment (LCA) and Quality Function Deployment (QFD) to support the redesign of existing offerings towards PSS	Environmental	Neramballi et al. (2020)
BESST-PSS	Connects four dimensions: PSS elements, life cycle, sustainability, and PSS value	Environmental, economic, and social	Sarancic et al. (2022)

multiple dimensions of sustainability. It is instrumental in pinpointing potential hotspots at various stages of the life cycle, which are characterized by their significant impact within the context of the entire value chain. These hotspots encompass not just environmental, but also economic and social aspects that are particularly relevant at specific points in the life cycle, as identified by Liedtke et al. (2013).

3.3.1. Hotspot analysis in the life cycle of products and services

Hotspot analysis is a qualitative tool designed to evaluate impacts across the life cycle of products and services and to identify significant aspects that need management throughout their life cycle (UNEP/-SETAC, 2014). It is often discussed in the literature as an initial step before conducting a full Life Cycle Assessment (LCA), offering a swift examination of various data sources, such as life cycle studies, market research, scientific literature, expert insights, and stakeholder input relevant to the life cycle (UNEP/SETAC, 2014). The outcomes of hotspot analysis can guide the identification of potential solutions and action prioritization to mitigate the most pressing economic, environmental, and social impacts or to capitalize on benefits related to a specific country, industry sector, organization, product portfolio, category, or service (UNEP/SETAC, 2014).

Methodologically, Sustainability Hotspot Analysis is structured into three phases (UNEP/SETAC, 2014).

(i) System boundary identification, involving the determination of life cycle stages and the environmental, economic, and social dimensions to be considered.
(ii) Relevance assessment of life cycle stages and the various aspects being evaluated.
(iii) Hotspots identification via an integrated analysis of the previous stages.

The process begins with defining system boundaries, which involves selecting the life cycle stages to be addressed, as well as identifying the environmental, economic, and social aspects to be included. Environmental aspects might include resource and energy use, water consumption, land use, waste generation, and emissions to air and water. Social aspects might involve working conditions, education, social security, health and safety, human rights, consumer health and safety, and product quality (Bienge et al., 2010; UNEP/SETAC, 2014).

In the product life cycle stages, the Sustainability Hotspot Analysis includes raw material extraction, processing, use, and end-of-service life treatment (Von Geibler et al., 2016). It covers all impacts related to the product and service, with indirect impacts, such as those related to transport, being allocated to the corresponding life cycle stages.

The second stage is the analysis of the relevance of the life cycle stages and sustainability dimensions using a scoring system from 0 to 3, where 0 indicates no relevance or insufficient information, and 3 indicates high relevance. This assessment is based on existing literature and studies about the product and service, including previous life cycle assessments and industry reports (Liedtke et al., 2010).

Following the relevance analysis, an assessment of the environmental and social aspects throughout the life cycle stages is conducted, applying the same scoring system. The score of 3 indicates high relevance and is assigned to aspects with the most significant impacts. Moderate relevance (2 points) is given to significant but less impactful aspects, and low relevance (1 point) to aspects with minor impacts relative to the life cycle stage analyzed (Von Geibler et al., 2016).

Hotspots are identified by multiplying the score of the life cycle stage by the score of the aspect within that stage (UNEP/SETAC, 2014). The highest-priority stages, indicated by scores of 6 or 9, are considered hotspots. The presence of multiple hotspots in a stage signifies a higher priority for examination and mitigation in the design process. To ensure the study's completeness and reliability, external stakeholders, especially those involved in the PSS, are consulted. Once hotspots are identified and verified, the design team can develop solutions to reduce impacts at these critical stages, optimizing the solution to avoid creating new impacts and considering other social and environmental aspects (Liedtke et al., 2013).

3.3.2. *Social Life Cycle Assessment (SLCA)*

Social Life Cycle Assessment (SLCA) is a method used to support decision-making regarding the social impacts associated with the life cycles of products (Jørgensen et al., 2012). SLCA facilitates the identification, comprehension, communication, and documentation of social impacts at every stage of a product's life cycle, thereby guiding strategies and action plans aimed at mitigating such impacts (Benoît et al., 2010). It adheres to the ISO 14040 technical framework (ISO 14044:2006, 2006) for LCA, which includes: (i) defining the study's goal and scope, (ii) conducting an inventory analysis, (iii) assessing impacts, and (iv) interpreting the results.

An SLCA examines the social and socio-economic effects across a product's life cycle, from "cradle to grave" (UNEP/SETAC, 2009). Each life cycle phase—and the individual processes within it—is tied to specific geographic locations where they take place, and at each location, various social and socio-economic impacts can be observed. Benoît et al. (2010) outline five main stakeholder categories that are impacted: (i) workers, (ii) local communities, (iii) society (at the national level), (iv) consumers (including end-users and those involved at each stage of the value chain), and (v) value chain actors (including suppliers). These stakeholder groups are integral to the hotspot analysis structured in this research, distinguishing it from other approaches like the SHSA, which do not consider these categories. Depending on the context, additional stakeholder categories may be delineated. UNEP/SETAC has defined more granular impact subcategories within these broader themes, designed to precisely delineate social areas of concern for each stakeholder group based on international agreements and best production practices. Table 6 in the document lists these recommended impact subcategories as per the UNEP guidelines.

4. Proposal of a hotspots-based approach for analysis of environmental and social hotspots in the life cycle of PSS

4.1. *Conceptual development of the hotspots-based approach*

The life cycle stages of the Product-Service System have been organized in accordance with the overarching stages of product and service life cycles, as described by Wiesner et al. (2015). This entails structuring the life cycle into the beginning of life (BoL), middle of life (MoL), and end of life (EoL) from the provider's perspective, consistent with stages suggested by prior research (e.g., Peruzzini and Germani, 2014; Wiesner et al., 2015). Operational phases have been addressed in a generic manner, encompassing product manufacturing, PSS implementation/use, and end of service life. Fig. 3 illustrates the structured life cycle stages of a PSS.

Environmental aspects are defined as components of an organization's activities, products, and services that can interact with the environment, potentially resulting in impacts, as delineated by ISO 14001 standards. Table 7 outlines the environmental aspects incorporated into the hotspot analysis approach. These aspects have been chosen for their generality, allowing for analysis across any PSS design, while additional, specific aspects may be introduced to tailor the analysis to particular situations.

Table 6
Stakeholder categories and impact subcategories.

Stakeholder categories	Subcategories
Workers/employees	Freedom of association
	Child labor
	Fair wage
	Work hours
	Equal opportunities/discrimination
	Health and safety
	Social benefits/social security
Consumer	Health and safety
	Social benefits/social security
	Feedback mechanisms
	Privacy
	Transparency
	Responsibility at the end of the product's service life
Local community	Access to material resources
	Access to immaterial resources
	Relocation and migration
	Cultural heritage
	Safe living conditions
	Respect for the rights of local communities
	Community engagement
	Local job generation
	Safe living conditions
Society	Community commitment to sustainability issues
	Contribution to economic development
	Conflict prevention
	Technological development
	Corruption
Members in the value chain	Fair competition
	Promoting social responsibility
	Relationships between suppliers
	Respect for intellectual property rights

Regarding the social dimension, given that a Product-Service System (PSS) involves a network of members throughout its life cycle, it is essential to consider the social impacts—positive or negative effects on the well-being of stakeholders (UNEP/SETAC, 2009). Stakeholder categories are defined as groups sharing common interests. In the context of a PSS, which is inherently systemic (Mont, 2002), social impacts on all involved parties must be accounted for. While the Sustainability Hotspots Analysis that forms the basis for this study's framework addresses social aspects in a broad manner without specifying the distinct groups affected during the life cycle, the SLCA method does differentiate the social impacts on various stakeholder groups, and this differentiation has been integrated into the hotspot-based approach proposed here.

Upon establishing the stakeholder categories, the SLCA literature was consulted to identify subcategories of social impact that are pertinent for consideration in the early design stages—these are the outcomes of the pressures on social parameters, particularly on stakeholder well-being. Selected were those subcategories that are relevant to the initial design phases and correspond to the type of PSS being developed, including the business model, products, and services involved. Table 8 lists the chosen categories and subcategories for this analysis.

Upon setting system boundaries, the next step is to compare life cycle stages against one another to evaluate their relative significance (identifying which stages may contribute most to environmental impacts) by using a scoring system, typically a 4-point scale as recommended by the Sustainability Hotspots Analysis (Liedtke et al., 2010; UNEP/SETAC, 2014). Many of the simplified life cycle assessment methods for integration into design, as identified in the literature review, employ similar scales (such as ABC Analysis, ERPA). A pairwise comparison of the life cycle stages should be conducted by the design team, taking into account the specific type of PSS being developed (e.g., its intended function, the products and services involved), along with available literature (such as previous life cycle studies of the involved products) and other secondary information (e.g., databases, technical industry reports) about the reference systems.

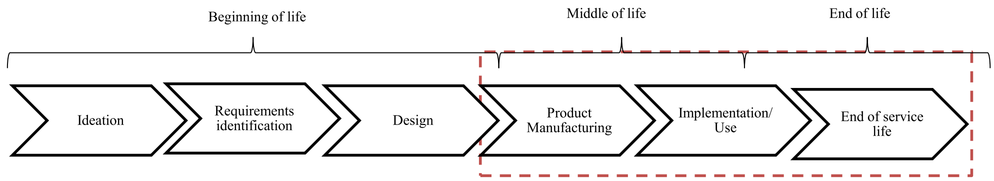

Fig. 3. Life cycle stages initially considered.

Table 7
Environmental aspects considered in the proposal.

Environmental aspects	References (PSS literature)	References (hotspot analysis literature)
Energy consumption	Chou et al. (2015); Sarancic et al. (2022)	Bienge et al. (2010); UNEP/SETAC (2014)
Water consumption	Chou et al. (2015)	Bienge et al. (2010); Liedtke et al. (2013); UNEP/SETAC (2014)
Generation of solid and liquid waste	Chou et al. (2015); Walk et al. (2023)	Bienge et al. (2010); UNEP/SETAC (2014)
Emission of pollutants (greenhouse gases)	Chou et al. (2015); Kim et al. (2016); Walk et al. (2023)	Bienge et al. (2010); Liedtke et al. (2013); UNEP/SETAC (2014)
Material consumption	Kim et al. (2016); Lee et al. (2012)	Bienge et al. (2010); UNEP/SETAC (2014)

Following the assessment of life cycle stages, the next phase is to analyze each social impact subcategory and each environmental aspect concerning the life cycle stages. The scoring scale for this analysis, ranging from 0 to 3 points, also follows the guidelines suggested by the SHA (Liedtke et al., 2013; UNEP/SETAC, 2014). To pinpoint social and environmental hotspots throughout the life cycle, the scores assigned to life cycle stages and those allocated during the assessment of social impact subcategories and environmental aspects should be integrated. Hotspots are identified by multiplying the scores assigned to each life cycle stage (for each dimension of sustainability) by the scores for each social impact subcategory or environmental aspect.

Values resulting from this multiplication that are 6 or 9 indicate that a social impact subcategory or environmental aspect is a hotspot at that life cycle stage and should be examined more closely in subsequent PSS design phases to minimize potential impacts. Once hotspots are identified, they should be critically reviewed by the stakeholders involved in the next design stages for assessment verification and to draw conclusions regarding the hotspots, as well as to establish an action plan for mitigating potential impacts. Documentation of all consulted sources for score allocation is crucial, both for the life cycle stages and for evaluating the relevance of environmental aspects and social impact subcategories.

Table 9 offers an illustrative fictive example for identifying and analyzing social dimension hotspots. For instance, if in the “product manufacturing” life cycle stage, the subcategories “health and safety” and “work hours” for the stakeholder category “workers” were scored 3 and 2 respectively, these scores would be based on data from the Social Hotspots Database, which indicated a high social risk for these subcategories in the region and industry involved in the product manufacturing stage.

Next, the identification of hotspots occurs by multiplying the scores assigned to each subcategory and life cycle stage. Equation 1 presents the procedure for identifying all possible hotspots throughout the life cycle.

$$X_{nxm} \text{ x } w_{mx1} = H_{nxm}$$

Where:

X_{nxm} - matrix of scores representing the assessment for the subcategories of social impact or environmental aspects throughout the life cycle;

n - subcategories of social impact or environmental aspect;
m - life cycle stages;
w - matrix of weights for life cycle stages; H - hotspot matrix.

The hotspot matrix is used to determine if a social impact subcategory or an environmental aspect qualifies as a hotspot within a particular stage of the life cycle being analyzed—if the value of Hi,j is either 6 or 9. The procedure for the environmental dimension follows a similar pattern. After the analysis is complete, the design team should engage with relevant stakeholders to establish an action plan. This plan will prioritize the hotspots and guide decision-making for the subsequent design stages of the PSS. Fig. 4 provides a synthesized depiction of the initial version of the structured hotspot analysis, illustrating the steps that the design team must follow during the early phases of a PSS development.

4.2. Results of the assessment conducted by PSS experts

Out of the 16 experts who were approached, ten provided responses; nine of these experts specialized in the research of Product-Service Systems, specifically in the assessment and design of a PSS, and one was an expert in life cycle assessment. The input gathered from the experts’ evaluations was utilized to refine the initial proposal. Many suggestions were given by more than one expert. Fig. 5 displays the updated structure of the life cycle and its respective stages, as revised following the experts’ recommendations.

Alongside modifications to the life cycle, alterations were also made to the stakeholder categories, social impact subcategories, and chosen environmental aspects. The hotspot analysis received an intermediate rating of "neither unsatisfactory nor satisfactory," with only half of the respondents assigning scores of 4 - satisfactory, or 5 - very satisfactory, based on criteria such as the depth of assessment, the clarity in identifying hotspots, the range of social impact subcategories and dimensions of sustainability considered, and the overall completeness of the analysis.

In terms of completeness, experts were queried about the method’s capacity to pinpoint environmental and social hotspots throughout a PSS’s life cycle. They recommended the inclusion of additional social impact subcategories and environmental aspects. On the matter of depth of assessment, the hotspot analysis, being qualitative in nature and reliant on existing studies and information on reference systems (Liedtke et al., 2010), has an inherent limitation in that it does not facilitate a detailed assessment akin to a full LCA. The experts’ views are understandable since the hotspot analysis is designed for a rapid overview and analysis of potential social and significant environmental impacts across the life cycle, typically serving as a preliminary step before developing more detailed sustainability data in subsequent project phases. This typically happens when more specific details about the product and business model have been fleshed out and more information becomes available. Thus, an in-depth analysis during the initial project stages is not feasible due to the absence of detailed information (Schöggl et al., 2017), nor is it the intended purpose of a hotspot analysis.

As for the social impact subcategories, the experts proposed numerous additions. Concerning clarity, a checklist containing guiding questions was developed to streamline the hotspot identification process. This checklist was grounded in literature on simplified life cycle evaluation methods for products, aiming to render the process more

Table 8
– Social impact categories and subcategories.

Categories	Subcategories	Description	Reasons/remarks	References
Workers	Health and safety	Means the promotion and maintenance of high levels of physical, mental, and social well-being and the protection of workers from risks	It can be related to the business model, industries involved in each of the stages of the life cycle, in addition to being related solely to the profile and practices of the organization	Chou et al. (2015); Hu et al. (2012); Lee et al. (2012); Lehmann et al. (2013); Peruzzini and Germani, 2014; UNEP/SETAC (2014, 2009)
	Work hours	Checks whether working hours comply with applicable laws and industry/sector standards	They can relate to the business model according to the type of activity to be conducted in each stage of the life cycle of a PSS and the location where the life cycle stage will be conducted	
Consumers	Health and safety	Concerns the products and services being safe during the stage of use	Relates to the types of products and services involved in the supply	UNEP/SETAC (2009); Hu et al. (2012); UNEP/SETAC (2014)
	Feedback mechanisms	Concerns the mechanisms through which consumers communicate with the organization and reveal their satisfaction	Certain types of PSS require high interaction with the consumer during the use stage, and a PSS needs to be monitored to ensure its functionality, availability, and results	UNEP/SETAC (2009); Lehmann et al. (2013); Chen et al. (2015)
	Privacy during use	Concerns mechanisms to respect and protect consumer privacy	There are PSS solutions where monitoring during the use stage is intensive	UNEP/SETAC (2009)
	End-of-service life liability	Concerns the efforts that must be made to address the social and public health impacts pertaining to the end of service life of the product or service	There are PSS solutions where end-of-service life responsibility is essential (e.g., in case of involving products with potential and significant environmental impacts)	UNEP/SETAC (2009)
Local community	Healthy living conditions	Assesses how organizations influence community safety and health	The impacts of operations also relate to the type of business model and the activities involved and how they impact the health, safety, and well-being of the community where they will be inserted	Hu et al. (2012); Lee et al. (2012); Lehmann et al. (2013); Peruzzini; Germani (2014)
	Access to material resources	Assesses the extent to which organizations respect, work to protect, provide, or improve access to material resources	A PSS aims to allow more individuals access to originally inaccessible products and improve access to infrastructure. It also relates to the type of PSS	UNEP/SETAC (2009); Sarancic et al. (2022)
	Access to immaterial resources	Assesses the extent to which organizations respect, work to protect, provide, or improve access to material resources	A PSS should encourage community engagement and promote technology transfer and skills development where it will be implemented	UNEP/SETAC (2009)
	Community Engagement	Refers to the engagement of community groups that may be affected by the actions of the organization or the products/services	A PSS should encourage the engagement of stakeholders in the community where it will be inserted to facilitate the economic development of the region	UNEP (2002); Lehmann et al. (2013)
	Job generation	Assesses whether the organization indirectly or directly affects local job generation	The type of PSS and the business model are also linked to generating local jobs. A PSS has the potential to generate jobs if the relationship with stakeholders is intensive	Hu et al. (2012); Lee et al. (2012); Lehmann et al. (2013)
	Cultural heritage	Assesses whether an organization respects cultural values and recognizes that members of the community where the solution will be inserted have the right to maintain their culture	The successful implementation of a PSS is extremely sensitive to be aligned with the cultural characteristics of the place where the solution will be inserted	UNEP/SETAC (2009), Lehmann et al. (2013); Chou et al. (2015)
Society	Public commitment to sustainability issues	Assesses organizations' engagement to reduce their impacts	In a PSS, the provider and the members involved must be motivated in their actions to encourage the reorientation of unsustainable consumption practices, especially in certain types of supply	UNEP/SETAC (2009); Lehmann et al. (2013)
	Economic development	Refers to how much an organization contributes to the economic development of a region and country	A PSS and its type of business model can contribute directly and indirectly to the economic development of the community where it will be inserted	UNEP/SETAC (2009)
	Technological development	Assesses whether the organization develops efficient and environmentally responsible technologies	A PSS must involve the use and development of advanced technologies both in the products and the production process	UNEP/SETAC (2009); Walk et al. (2023)
Members in the value chain	Relationship between members	Concerns the unintended impacts and consequences that an organization's decisions can have on other organizations	The type of business model can contribute to the strategic positioning and competitiveness of organizations involved in the value chain	Mont (2002)

transparent and straightforward. Review of the literature indicated that checklists are a common feature in various methods and tools (e.g., MET-Matrix, ERPA), enhancing applicability by providing clear procedural guidance (Byggeth and Hochschorner, 2006), and are also time-efficient in pinpointing specific environmental aspects (Kishita et al., 2010).

4.3. Inclusion of a checklist to guide the assessment

Table 10 presents the checklist created to facilitate the analysis of aspects within the environmental dimension.

In the social dimension, the guidelines from UNEP/SETAC (2009) and literature on SLCA (Benoît et al., 2010) supported the development of the checklist shown in Table 11.

Based on expert feedback, the following enhancements were implemented.

i) Life cycle: Integration of new stages such as raw material extraction, segmentation of the Middle of Life (MoL) stages, and the proposal to construct scenarios for the End of Life (EoL) stage were taken into account.
ii) Stakeholder categories: No categories were removed.

Table 9
Example of structuring the analysis of hotspots for the social dimension.

Life cycle stages of a PSS		Product manufacturing	Implementation/ Use	End of life
Social dimension (weights of life cycle stages)		3	2	2
Workers	Health and safety	3 (hotspots = 3 x 3)	1	1
	Work hours	2		
Consumers	Health and safety	3		
	Feedback mechanisms	0		
	Privacy during use	0		
	End-of-service life liability	0		

iii) Social impact subcategories: Within the 'consumers' group, one subcategory was eliminated, and another was added to the 'society' group.
iv) Specific subcategories relevant to particular contexts have been identified for inclusion where applicable.
v) Environmental aspects: The analysis of PSS literature led to the addition of "consumption of renewable resources" and "use of harmful materials" as environmental aspects.
vi) To refine the framework of the proposal, a checklist was created to aid in the analysis process, enhancing the precision in hotspot identification.

Fig. 6 depicts a comprehensive view of the revised, second version of the proposed hotspot-based approach, including the processes for identifying and analyzing hotspots.

As previously mentioned, in the process of determining the system boundaries, the design team evaluates potential scenarios for the end of the service life based on the updated life cycle structure. The identification of stakeholder groups, social impact subcategories, and environmental aspects can be tailored during the system boundaries definition stage to fit each specific design case. The analysis phase is facilitated by a checklist specifically devised to guide the scoring process.

The proposed hotspot analysis differs from existing lifecycle assessments already proposed for application in PSS contexts. An LCA is more appropriate for later development phases when product specifications and other variables are established. This distinction underscores the unique contribution of the proposed approach to early design phase practices. It views the operational life cycle stages from the perspective of a provider, honing in on stages where members have direct influence (Liedtke et al., 2010).

In terms of impact categories, LCA incorporates numerous environmental impact categories. In contrast, the proposed approach selects

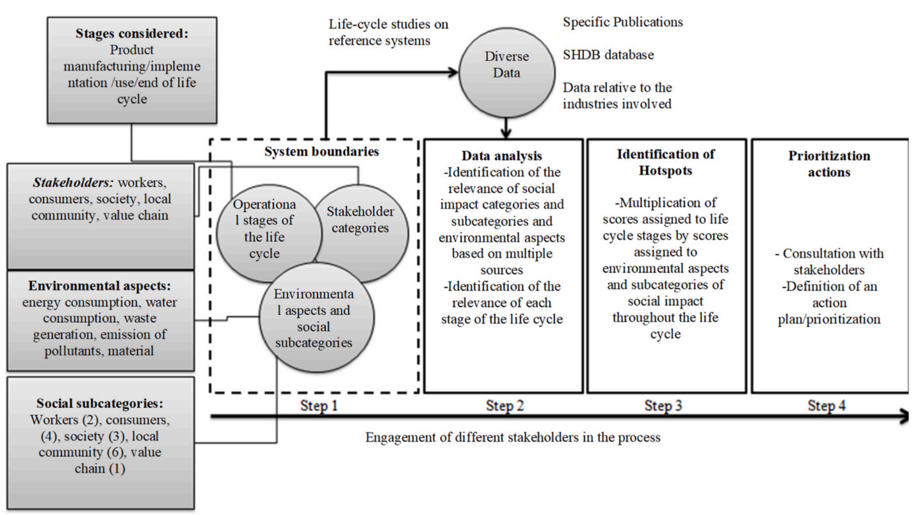

Fig. 4. First version of the proposed hotspot analysis.

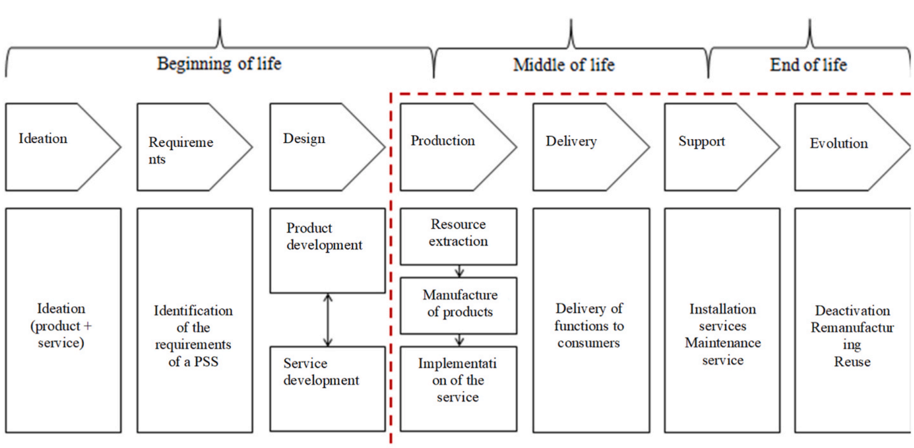

Fig. 5. Structuring of the life cycle after assessment by experts.

Table 10
Checklist to guide the identification of hotspots in the environmental dimension.

Environmental aspects	Suggested questions to guide the review process	Suggested indicators	Support references
Energy	Is it necessary to consume energy to conduct the respective life cycle stage? Is there fossil fuel consumption? Can there be considerable energy consumption for product handling? Are materials used that involve considerable energy consumption (e.g., aluminum)?	Energy consumption	Bienge et al., 2010); UNEP/SETAC (2009); Liedtke et al. (2010); Arena et al. (2013); Kim et al. (2016); Zhang et al. (2021)
Water	Is it necessary to consume water to conduct the respective life cycle stage? Can there be considerable water consumption for product handling?	Water consumption	Bienge et al. (2010); Liedtke et al. (2010); Arena et al. (2013)
Renewable resources	Is it relevant to use renewable energy sources to carry out the respective life cycle stage?	Energy consumption	Byggeth et al. (2007)
	If water is a significant issue in your market, are there alternative sources of water that could be used at the respective life cycle stage?	Water consumption	UNEP/SETAC (2009)
Waste	Do the outputs of the respective life cycle stage generate pollution and waste? Can waste generation be minimized?	Types and quantities of waste generated	Byggeth et al. (2007); Arena et al. (2013); Walk et al. (2023)
Toxic materials	Is there a risk of handling harmful substances?	Types and quantities of harmful materials used	Arena et al. (2013); Byggeth et al. (2007)
Emissions/effluents	Do the product and its materials contain toxic gases that can be released during the life cycle stages? Do emissions to water occur?	Types and quantities of pollutants emitted into air/water	Arena et al. (2013); Kim et al. (2016); Zhang et al. (2021)
Materials	Is there a high consumption of materials in the respective life cycle stage? Is consumption efficient?	Types and quantities of materials consumed	Arena et al. (2013); Kim et al. (2016); Zhang et al. (2021)

those environmental impact categories (e.g., energy consumption; water consumption; generation of solid and liquid waste; emission of pollutants/greenhouse gases; and material consumption) that are most prevalent in PSS literature and sufficiently broad to apply to any type of PSS development. This approach also integrates the social dimension, expanding beyond the environmental focus of traditional LCA. In this way, the social impacts were considered for the entire network of involved actors, including workers, consumers, the local community, and society. This more human-centered perspective is scarce in the literature so now represents a unique feature in this work.

It is suggested that the environmental aspects and social impact subcategories proposed in this work be contextually adapted for each specific case, whereas conventional LCA tends to be restricted to predefined categories, often supported by database information. This analysis avoids the weighting and data aggregation seen in LCA, as it operates on a qualitative basis, spotlighting potential key impacts to aid decision-making during the initial design phase. When multiple products are implicated and receive varying scores within a life cycle stage, the approach advises adopting the higher score for the impact category at that stage to highlight the hotspots. However, prioritizing hotspots is not included in the proposed method; it is up to the design team to determine priority according to the specifics of the case.

Data arbitrariness is acknowledged in both hotspot analysis, based on the design team's qualitative or semi-quantitative assessment, and LCA, which involves a degree of arbitrariness in impact aggregation. Nonetheless, both methodologies strive for transparency in deriving results. A checklist is provided to guide the review process, and documentation of all decisions is recommended.

The hotspot analysis does not incorporate temporal data indicating when impacts occur, but it does use geographical information, particularly for social impacts—a level of detail not typically distinguished in LCA. Although both methods can be applied globally, hotspot analysis is notably simpler and more time-efficient for initial design stages, where detailed information may be scarce and sustainability expertise is not yet engaged. The interpretability of hotspot results is straightforward—identifying hotspots without requiring in-depth LCA knowledge—and the data collection is less time-consuming than a full LCA. This aspect is beneficial during the early phases of PSS development when resources are limited. The results from hotspot analysis provide a generic overview of potential impacts, forming a foundation for a more comprehensive life cycle analysis to be undertaken once further details of the products/services and organizations are defined.

5. Discussion

The development of the proposed approach allowed further conclusions regarding the design of sustainable product-service systems and the sustainability assessment of such systems. First, it was found in the literature review that there is no consensus on the phases involved in the life cycle of a PSS. Publications suggest phases associated with the life cycle of products and services in an integrated manner, but there is no consensus on the life cycle phases and respective divisions (MoL, BoL, and EoL). Regarding environmental aspects, there is also no consensus on which aspects are most relevant to be analyzed in the context of a PSS solution (overall), as a range of environmental aspects is considered in the publications. For the social dimension, existing publications address the social impacts on workers involved in the PSS and consumers, only. Other stakeholders involved in the system are left out, despite the acknowledgment on the "system" aspect of a PSS solution. The proposed approach sheds light on those unacknowledged aspects of PSS design, i.e., what constitutes a PSS lifecycle and the impacts on a broader network of actors. Also, to ensure applicability in the design of any category of PSS, the proposed approach includes a range of environmental aspects, stakeholder categories, and subcategories of social impacts. This makes the proposed approach more applicable then previous suggested methods in the existing literature, that often not even acknowledge that adaptations of the proposed method/tool is needed depending on the context of application and PSS category or type. The consultation with experts concluded that there is indeed no consensus on which subcategories of social impact and groups of stakeholders are most appropriate to address in the early design phases, and that considerations about specific stakeholder categories and subcategories of social impact need to be made before proceeding with the application of the proposed approach, in the phase of identifying system boundaries. The evaluation conducted by the experts also confirmed that methods and tools need to

Table 11
Checklist to guide identifying hotspots in the social dimension.

Stakeholder categories	Social impact subcategories	Proposed questions to guide the process of identification and hotspot analysis	Suggested indicators	Possible sources of information
Workers	Health and safety	Does the work conducted in the respective life cycle stage pose risks to the health of workers? Is the rate of accidents at work in the country/region/industry high?	Social risk of occupational accidents in the region	Social Hotspots database
	Work hours	Does the respective life cycle stage involve intensive work processes? Are the industries/regions where the life cycle stage is characterized by excessive working hours?	Social risk for excessive working hours in the region	Social Hotspots database, International Trade Union Confederation WTO country report
Consumers	Health and safety	Are there a significant number of complaints regarding the products involved or the conventional business model at the industry/national level? Are there a large number of accidents involving related products with regard to their effects on health and safety?	Existence of complaints in the industry	Industry Reports
	Feedback mechanisms	Are feedback mechanisms relevant in the life cycle under analysis? Is the number of consumer complaints relevant in the context of existing products/services/business model?	Existence of complaints in the industry	Industry Reports
	End-of-service life liability	Can disposal of the product or other end-of-service life schemes lead to significant environmental and social concerns? Is there regional/national legislation responsible for the final disposal of the product/recycling?	Existence of legislation on the disposal at the end of the service life of the products	Ecolex information on legislation in each country
Local community	Health and safety	Can the realization of the life cycle stage affect the health and safety of the community? Are there safety regulations that must be followed in the region where the life cycle stage will be implemented? Are the pollution levels in the area high?	Pollution level in the region/health and safety regulations in the region	World Bank
	Access to material resources	Is the percentage of the population with access to basic sanitation in the locality where the life cycle stage will be implemented relevant? Is there infrastructure? Is the development of local infrastructure relevant to the population's quality of life?	Statistics on access to water and sanitation infrastructure	Social Hostpots Database
	Access to immaterial resources	Are there free speech policies in the locality where the life cycle stage will be implemented? Are they relevant? Are there policies for technology transfer?	Levels of technology transfer in the region	World Economic Forum
	Community Engagement	Is the engagement of local members fundamental to conducting the life cycle stage?	Transparency of the public policy-making process	World Economic Forum
	Job generation	Is job generation with the completion of the life cycle stage extremely relevant in the region? Are unemployment statistics in the region/country high?	Unemployment statistics in the region/ industry	Social Hotspots Database/ ILO database
	Cultural heritage	Are there specific cultural values in the place where the life cycle stage will be realized that need to be maintained?	Characteristics of the place where the life cycle stage will be conducted	Cultural information of the region
Society	Public commitment to sustainability issues	Are the industries related to the products/services involved engaged in sustainability issues? Is this aspect relevant to the life cycle stage under analysis?	Engagement of the industry involved in sustainability issues/existence of an obligation to prepare environmental reports	Government/Industry Reports
	Economic development	Do the industries in the respective life cycle stage contribute significantly to the local economy?	Economic situation of the country/ region/relevance of the industry involved to the local economy	National economic statistics
	Public policies on sustainable development	Are there public policies to promote sustainability relative to the industries involved? Is the existence of such policies essential for the implementation of the PSS?	Existence of public policies	Industry/government reports
	Technological development	Does the completion of the life cycle stage contribute significantly to technological development? Are industry efforts for technology development relevant?	Industry efforts in the development of new technologies	Industry Reports
Members in the value chain	Relationship between members	Does the realization of the life cycle stage significantly impact other members in the value chain?	Economic statistics on related industries in the value chain	Industry Reports

be simple and quick to apply in the early design phases (which is not the case of a range of complex PSS methods and tools suggested in the existing literature), and that the analysis process needs to be guided, as the team involved in the design of a PSS may not be experts in sustainability issues. A checklist to guide the analysis phase of environmental aspects and subcategories of social impact was developed in this study, aiming to support its applicability in practice.

The proposed hotspot analysis framework combines life cycle assessment techniques to pinpoint stages in the PSS life cycle where significant environmental and social impacts may occur, providing thus a novel approach to sustainability assessment in the context of PSS design, which also represents a contribution to social lifecycle assessment literature as most of existing research and methods available are dedicated to assessing products (UNEP/SETAC, 2014). This research then represents an advancement in the literature and what was proposed by UNEP, given the focus on product-service system design, by redirecting the emphasis that predominantly lies on product development. From a PSS perspective, the contributions to existing PSS literature are multifaceted. Firstly, the study expands the understanding of sustainable PSS design by offering a structured method for early identification and assessment of potential sustainability hotspots (Lee et al., 2012; Moro et al., 2022). By incorporating social sustainability dimension into the assessment, the study enriches the PSS literature, which has historically emphasized environmental and economic dimensions over social ones. This contribution addresses the noted absence of comprehensive tools for early-stage PSS sustainability evaluation, especially tools that integrate social sustainability considerations alongside environmental impacts. The framework developed provides designers and

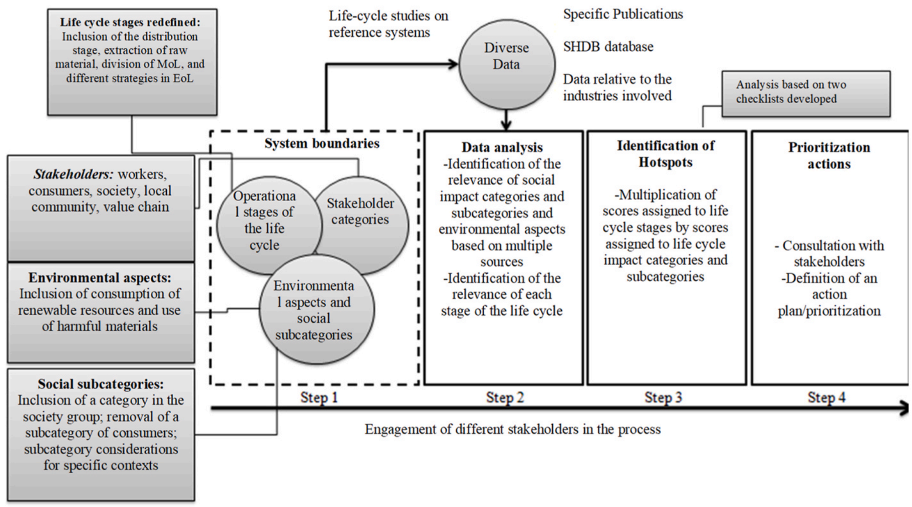

Fig. 6. Second version of the proposed hotspot analysis.

decision-makers with insights into potential impacts at a stage when modifications to the design are still feasible and less costly, facilitating the development of more sustainable PSS solutions. Furthermore, the inclusion of expert evaluations in refining the hotspot analysis framework underscores the practical relevance and applicability of the proposed method, enhancing its validity and utility in real-world PSS design scenarios. Thus, the study not only fills a critical gap in the literature by providing a methodological approach to integrate environmental and social sustainability considerations in the early stages of PSS design, but also sets a new direction for future research in the field. By highlighting the importance of early-stage assessments and the need for holistic sustainability evaluations, the study paves the way for further exploration of sustainable PSS designs that fully embody the principles of sustainable development.

6. Conclusions

This research endeavors to bridge significant gaps identified in the domain of sustainable solutions, particularly within the ambit of Product-Service Systems. It seeks to remedy the persisting challenges in evaluating PSS from a holistic life cycle perspective during the nascent stages of design—a task made arduous by the scarcity of comprehensive information and a prevailing inclination towards the environmental aspect of sustainability. Such an inclination, while beneficial, often sidelines the equally crucial social and economic dimensions of sustainability, thereby underscoring the imperative for methodologies that encapsulate all facets of sustainability.

This study marks a significant leap towards this goal by introducing a novel hotspots-based approach, which integrates the life cycle view with an emphasis on the social sustainability dimension of PSS. This methodology not only paves the way for informed early-stage design decisions but also enhances the evaluation of varying PSS concepts, ultimately facilitating the crafting of truly sustainable solutions. Consequently, this approach significantly contributes to the PSS literature by addressing a critical void and advancing the application of a life cycle perspective at preliminary design junctures.

Nevertheless, it is crucial to acknowledge the inherent limitations of our proposed methodology. These limitations arise from the conceptual underpinnings of the approach, the literature review process — which may have inadvertently constrained the research scope — and the selection criteria for expert reviewers, which predominantly included academics from the sustainability field. This composition of the review panel may introduce a potential bias, despite achieving saturation. Additionally, the reliance on the design team to prioritize identified hotspots introduces a requirement for specialized expertise, suggesting an opportunity for the incorporation of multicriteria analysis to aid this prioritization process. Future research directions include the integration of the three pillars of sustainability — environmental, social, and economic — for a more holistic life cycle assessment in PSS design and the practical application of the hotspot analysis to identify real-world challenges faced by design teams. Through such endeavors, we aim to further the development of comprehensive and pragmatic sustainable design solutions, thereby contributing to the overarching goal of sustainability in the design and implementation of Product-Service Systems.

CRediT authorship contribution statement

Thayla Tavares Sousa Zomer: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Paulo Augusto Cauchick-Miguel:** Supervision. **Eloiza Kohlbeck:** Writing – original draft. **Suzana Regina Moro:** Writing – original draft. **Eduardo de Senzi Zancul:** Writing – original draft. **Glauco Henrique de Sousa Mendes:** Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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